



**US Army Corps
of Engineers**
Waterways Experiment
Station

Ship Navigation Simulation and Current Modeling Study, Savannah River, Georgia

by Gary C. Lynch, Keu W. Kim

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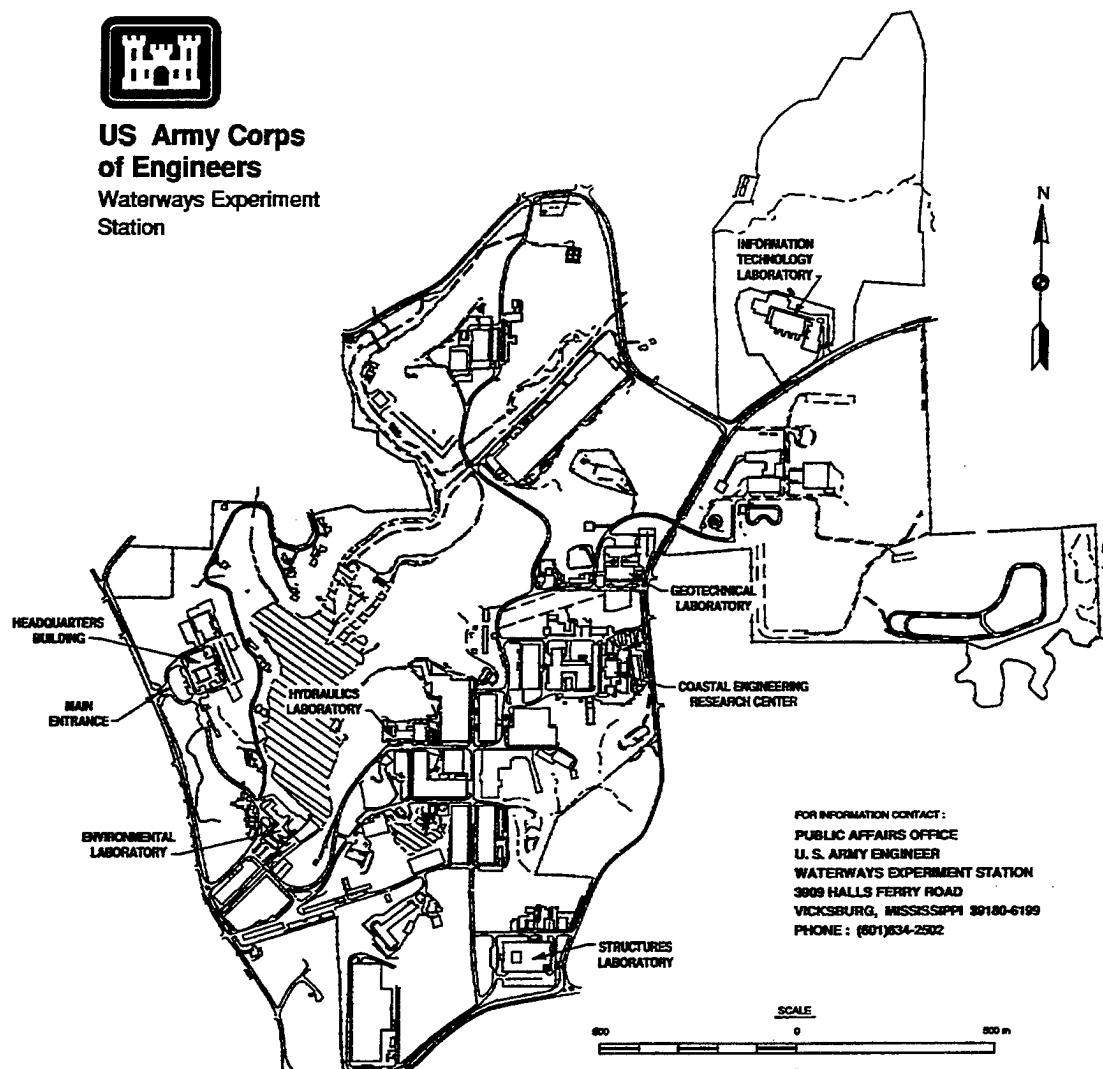
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Preface

This navigation study was performed by the Hydraulics Laboratory (HL) of the U.S. Army Engineer Waterways Experiment Station (WES) for the U.S. Army Engineer District, Savannah. Simulator testing performed with the Savannah Harbor pilots was conducted with the WES ship/tow simulator ending 28 March 1992. Current modeling was conducted by the Estuarine Processes Branch, Estuaries Division, HL.

The navigation study was performed by Mr. Gary C. Lynch of the Navigation Branch, Waterways Division, HL, under the general supervision of Messrs. Frank A. Herrmann, Jr., Director of the HL; Richard A. Sager, Assistant Director of the HL; and Dr. Larry L. Daggett, Acting Chief of the Waterways Division. Ms. Donna Derrick, Civil Engineering Technician of the Navigation Branch, and Ms. Debbie Wilkinson, Contractor, CSC Professional Services, Inc., assisted in the study. The current modeling study was performed by Dr. Keu W. Kim, Estuarine Simulation Branch, Estuaries Division. This report was prepared by Mr. Lynch and Dr. Kim.

Acknowledgment is made to Mr. Carl Huval, Navigation Branch, and Messrs. Wade Seyle and Frank Posey, Coastal and Waterways Engineering Section of the Savannah District, for cooperation and assistance at various times throughout the investigation. Special thanks go to the Savannah Pilots Association, Crescent Towing and Salvage Company, and Turecamo of Savannah, Inc., for providing pilot participation in the study.

At the time of preparation of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers
pounds (force) - second per square foot	47.88026	pascals - second

1 Introduction

Savannah Harbor

Beginning at the Atlantic Ocean and traveling northwest, the Savannah Estuary divides Georgia and South Carolina (Figure 1). The Savannah Harbor Deepening Study encompasses the Savannah Harbor from Kings Island Turning Basin on the Front River downstream to midway along Bird Island on the North Channel (Plate 1). Savannah Harbor includes 21.3¹ miles of the Savannah River beginning approximately 18 miles east of Savannah, Georgia. The harbor is a narrow winding river subject to both freshwater inflow and tidal action. A tide gate and a sediment basin are located on Little Back River (Plate 2). At the time of testing, during flood tide, the tide gate was open and a good portion of the sediment that deposited along the North Channel during the previous slack phase was resuspended and carried into the sediment basin where it was deposited. During ebb tide the tide gate was closed. The closed gate forced all ebb flow to use the Front River increasing velocities and causing resuspension and flushing of the sediment deposited in the Front River during slack water. This resulted in reduced maintenance dredging along the Front River Channel. On November 15, 1991, a modification was authorized to take the tide gate out of operation and close New Cut. New Cut closure was completed in February 1992. To allow a more detailed look at each of the subareas, the study area is divided into five subareas, called insets (Plate 3).

The Hydraulics Laboratory at the U.S. Army Engineer Waterways Experiment Station (WES) conducted various numerical studies to determine variations of currents and salinity of the Savannah River Estuary. A study by Hewlett, Daggett, and Heltzel (1987) modeled the upper reaches of the Savannah River using the two-dimensional (2-D) Vertically Averaged model (RMA-2V). Johnson et. al. used the Laterally Averaged model (LAEM) to study the proposed channel deepening impacts on salinity intrusion and shoaling along Front River (Johnson, Trawle, and Kee 1989). Due to concerns about lack of salinity verification in the upper reaches of the estuary, an intensive effort was

¹ A table of factors for converting non-SI units of measurement to SI units is found on page v.

made to collect prototype data, and to refine the existing LAEM of the area under a wide range of conditions (Evans 1991).

Existing Conditions and Navigation Problems

Current project depth in the harbor is 38 ft, hereafter called Base conditions, and the design depth is 42 ft, called the Plan condition. This study addresses the impact of the navigation channel dimensions, ship maneuverability, underkeel clearance, and natural channel restrictions on the deepened channel design. Also studied, in addition to the deepening, were two changes that affect ship navigation: the permanent opening of the tidal gate on Back River, and the permanent closure of New Cut, upstream of Kings Island Turning Basin.

The main areas of concern for navigation in the Savannah Harbor Deepening study were as follows:

- a. Constriction of the channel between Fort Jackson and the "CSS Georgia" wreck site.
- b. Turning maneuvers at Kings Island Turning Basin.
- c. Ship maneuverability near the LNG terminal and turning basin.
- d. Ship maneuverability near the Highway 17A Bridge and Hyatt Hotel.
- e. Ship maneuverability upstream of the LNG terminal in the River Bight area.

2 Hydrodynamic Model

Objective and Scope of Current Model (Hydrodynamic) Study

A 2-D hydrodynamic model study of the middle portion of the Savannah River Estuary was needed to support a proposed ship simulation study. This study required a 2-D vertically averaged model that can determine lateral current variations in the multiple connected channels of the region. A study of Hewlett, Daggett, and Heltzel (1987) modelled the upper reaches of the Savannah River Estuary using the 2-D vertically-averaged model, RMA-2, but this reach did not extend downstream far enough to cover the desired area for this project. Evans (1991) conducted a detailed model study of the region using the 2-D laterally-averaged model LAEM but this, by definition, would not suffice for the purposes of a ship simulation study. However, substantial analysis of collected field data was accomplished by Evans that was invaluable for generating boundary conditions and validation data sets for the proposed study.

Hydrodynamic Approach

Since lateral variations of currents in the interconnected channels of the region are important to the navigational safety of the vessels in the channel, the modeling tool used to predict the hydrodynamics of the Savannah River was RMA-2V of the Corps' TABS-MD modeling system. TABS-MD is the name of a family of generalized computer programs and utility codes integrated into a numerical modeling system to study hydrodynamics, sedimentation, and constituent transport in rivers, reservoirs, bays, and estuaries. RMA-2V, a component of the TABS-MD system, is a finite element solution to the Reynolds form of the Navier-Stokes equations for turbulent flows and can accurately predict circulation in the interconnected channels. A detailed description of TABS-MD can be found in Thomas and McAnally (Thomas and McAnally, Jr., 1985).

The entire Savannah River Estuary from the Atlantic Ocean and Ebeneezer Landing, some 45 miles upstream at the head of the tide, was modeled for the

hydrodynamic part of this study (Figure 2). The RMA-2V model included all significant features, such as secondary channels, the sediment basin, and any marsh areas that could affect ship navigation. Tide data from the U.S. Geological Survey (USGS) gage at Fort Pulaski and freshwater inflows upstream of Ebeneezer Landing were defined as the boundary conditions for model verification. Comparing field data and model results determined model validity. After obtaining the existing conditions validity, the average freshwater inflow and extreme spring-tide range Base and Plan conditions were simulated for three geometries as follows:

- a. The existing conditions of Savannah Harbor's existing maintenance profile and the operation of the tide gate.
- b. The Base conditions in New Cut (drainage channel between Middle River and Little Back River at Argyle Island) were closed and 38-ft channel depths were used with the flood gate open throughout the tide cycle.
- c. The Plan conditions in New Cut were closed and the present ship channel was deepened to 42 ft with the flood gate open throughout the tide cycle.

Hydrodynamic Model Generation

The hydrodynamic model covered a period of 45 hours and included a 4-hour "spin-up" and a 41-hour spring-neap cycle. A time invariant freshwater inflow of 8,744 cfs was specified at the riverflow boundary condition for Ebeneezer Landing. A dynamic boundary condition at the ocean boundary was specified and was synthesized from National Ocean Service (NOS) harmonic constituents, with hour 0 equal to 0700 on 19 January 1992. Eddy viscosity values were based on cell size and Peclet number (or cell Reynolds number, $P=1.94UL/e$, U = average velocity, L = average length, e = eddy viscosity). Wetting and drying options in TABS-MD simulated flow over the marshes. Elements were assigned to specific groups based on size, location, and average depth. Since all the elements of a specific group were not generally oriented in the same direction, the hydrodynamic model viscosity was selected by the average greatest length of each element in a group. An initial estimate of 100 was used for the Peclet number to generate the viscosity values. Changing these values to verify the model also changed the final Peclet values. Roughness coefficients were based on water depth, bottom material, and presence or absence of vegetation. The viscosity, roughness (Manning's n), and element dimension for each group are listed in Table 1.

Table 1**Viscosity, Roughness (Manning's n), and Element Dimension**

Element Group	Viscosity 1b-sec/ft ²	Manning's n	Avg. Element length (ft)	Type of element
1	75.0	0.016	900.0	Main Channel
2	100.0	0.160	850.0	Marsh Area
3	100.0	0.020	1400.0	South Channel
4	70.0	0.016	900.0	Secondary River
5	40.0	0.025	700.0	Middle and Back River
6	25.0	0.025	500.0	Backwater and Slips
7	40.0	0.016	500.0	Front River
8	20.0	0.016	250.0	Front River near Ft. Jackson
9	35.0	0.016	700.0	Sediment Basin
10	200.0	0.016	2000.0	Ocean and Jetties

Description of Hydrodynamic Model Tests

Model runs were initiated from a cold start with a water-surface elevation of 8.5 ft Mean Low Water (MLW) for a 4-hour transient period of RMA-2V to fully distribute the effects of the imposed tidal boundary conditions throughout the study area. Fort Pulaski observed tide data were used for the boundary at the ocean end of the model. Because this station was inside the tidal boundary, frictional losses were regulated by shifting the tide 11 minutes and adjusting the tidal amplitude. The discharge measurements at Clyo provided the freshwater discharge boundary at the upstream end of the model, near Ebeneezer Landing. Clyo is upstream of Ebeneezer Landing so the flow was increased 10-15 percent and the time was lagged two days to account for extra drainage area and distance between the two points.

To verify a hydrodynamic numerical model, a number of locations where the water-surface elevation and velocity are recorded simultaneously over one or more tidal cycles is preferable. This is known as synoptic data. Water-surface elevation and current data for seven stations were obtained from 7:30, 30 October 1991, through 20:30, 30 October 1991. Figure 3 shows the location of gage stations where survey data were obtained. Plate 4 shows the location of RMA-2V nodes used for data comparison in this report.

Each simulation consisted of a two-tide lead-in followed by the design tide for the spring range with maximum current speeds and directions distilled from them. These currents were used to develop the current database for the

navigation simulation, that covers only the navigation channel in the study area. Verification of the current and water-surface elevation computations in RMA-2V was accomplished by the field data sets collected in October 1991 at the seven locations. Figures 4-17 show the comparison of this survey data and the model predictions. In analyzing these results it must be considered that the RMA-2V velocities are depth averaged, while the field data velocities were taken 1 ft below the surface and 1 ft above the bottom with no mid-depth velocities measured. Also, the direction of field data flow was specified as either flood or ebb based on surface motion. However, these conditions were sufficient for use in verifying the model for this study. The comparison of currents at stations 1, 5, and 6 were of particular interest.

The currents, once integrated into the navigation simulation model (shown on Plates 5-24), were validated again with the cooperation of the pilots involved in testing. Any problems expressed by the pilots about the currents were verified with historical data to determine whether the currents were realistic. No changes were required for most of the harbor; however, two changes were required for the Kings Island Turning Basin. Due to the size of the TABS-2 finite element grid required by the large study area, the docking facilities could not be modeled in detail. This led to currents of an increased magnitude on the western side of the turning basin, the failure to reproduce an eddy in the northeastern corner of the basin during the ebb tide, and a slight increase in current magnitude in the southeastern corner of the basin during flood tide. The currents were modified to the pilot's satisfaction so that the conditions in the prototype were reproduced in the model. These current changes are seen on Plates 5, 10, 15, and 20.

Results of the Hydrodynamic Model

Figures 18-25 compare water-surface elevations and velocities between existing and Base conditions at eight locations along the Savannah Ship Channel. Also, they show that closing the New Cut and opening the tide gate decreased velocities slightly and that the tidal range was not changed significantly. Figures 26-33 show the predicted tide and velocities for the Plan and Base conditions for a 16-hour period. The velocity comparisons show that deepening the navigation channel will have a very minor impact upon velocities. However, the water-surface elevation comparisons show that this deepening will result in a slight increase in tidal range. Comparisons between Existing and Plan condition velocities are shown on Figures 34-41. These results indicated that closing the New Cut, opening the tide gate, and deepening the navigation channel decreased the current velocities due to the increase in cross-sectional area. Results also indicated that the tidal range will increase slightly.

3 Navigation Model

Objective and Scope of Navigation Study

After discussions with Messrs. Miller, Seyle, and Posey of the Savannah District, Messrs. Holler and Orsak of the U.S. Army Engineer Division, South Atlantic, and Messrs. Huval and Lynch, and Dr. Daggett of the WES, the following steps were proposed for the Navigation Study:

- a. Receive hydrodynamic model study currents for the study area in the Verification, Base, and Plan Conditions.
- b. Analyze information (aerial photographs, hydrographic surveys, NOAA charts, etc.) and produce a radar and visual scene database for the ship simulator. The database consisted of two parts: the first part began approximately one mile downstream of Fields Cut and continued upstream to just past the new Highway 17A Bridge; and the second started approximately one mile downstream of the Kings Island Turning Basin including the turning basin. The first database addresses the majority of the regions of concern; the second database addresses maneuvering in the Kings Island Turning Basin.
- c. Construction of a ship model for the HANJIN class design ship.
- d. Incorporate the currents from the hydrodynamic model for the Base condition into the ship simulator database.
- e. Verification of the simulation model with the design ship by two Savannah area pilots.
- f. Incorporate the hydrodynamic model currents for the proposed channel into the ship simulator database.
- g. Have six Savannah area pilots run a testing series on the Base and the proposed channels.
- h. Analyze test results.

- i. Prepare analysis of underkeel clearance with respect to squat and wave effects.
- j. Provide the District with preliminary results.
- k. Prepare a report on the findings.

Simulation Database Generation

Required data. Data required for a simulation study included channel geometry, bottom topography (bathymetry), channel currents, design ships, and visual data of the physical scene for Base and Plan conditions. The method for developing each of these is described in the following paragraphs.

Visual scene. The creation of the visual scene database for Savannah Harbor was mainly derived from the Annual 1990 Survey of Savannah Harbor, Georgia. The District also supplied newer survey charts for the widened areas of the channel. The aerial photographs for these survey charts were taken in 1988; therefore, revisions were needed in the placement, addition or deletion of buildings, structures, bank shape, etc. WES made a reconnaissance trip at the initial phase of the study and a video was taken during two ship transits that aided in the revisions. Also documented were pilot comments on different areas of the channel while in transit so a general understanding of navigation conditions was obtained. This information helped in preparation of the simulation before the pilots came to WES for verification. Some revisions were also made from the docking and river pilots' comments during the verification testing period. All features such as bank line configuration, buildings, docks, towers, bridges, etc. were input to an AutoCAD file in X, Y, and Z coordinates. These features were then run through a preprocessor for input into the Silicon Graphics 3000. Finally, the Silicon Graphics 3000 generated the visual scene for the Harbor area and was displayed on a large screen projector. The current simulator setup is shown in Figure 42.

Radar scene. Similarly, the radar file came from the digitized bank line shape of the Savannah Harbor CAD file that was created for the visual scene database. It was preprocessed and the resulting database loaded into the PC executing the radar simulation. The radar database only contained information normally available on a ship's radar readout. This radar image counteracts part of the disadvantage when a 2-D screen is used to view a three-dimensional visual scene. Like a true radar image, angles and ranges to points are also found on the radar screen. For this study, four radar ranges were available. The one-quarter-mile-range screen was visible at all times and also displayed the tug placement and force when this option was used in the turning basin. The other radar screen was adjustable between the 0.5, 0.75, and 1.50 mile ranges. Tug placement and availability is dependent upon what is available in the prototype. Figure 43

shows the various placements that can be used with the simulator. Tugs at these locations can be placed at any angle in a push or pull state at varying degrees of thrust.

Channel geometry. Channel geometry was created from both the hydrographic surveys supplied by the District office and the information received from the hydrodynamic model. Included in this group of files is the bathymetry of the channel, definition of bank conditions, current magnitude and direction, and any pertinent environmental data such as wind or waves. These data are input into the VAX 11/750 along with initial settings for the vessel used in simulation.

Ship files. Ships used during the testing procedure included a New York class and a HANJIN class containership. The New York class represents ship sizes presently using the harbor and are 950 ft long overall, the length between perpendiculars is 915 ft, and the beam at midships is 106 ft. The HANJIN class ship has an overall length of 961 ft, a 106-ft beam, and represents future expected ship sizes. Draft of both ships for Existing and Base conditions was 36 ft while the Plan condition draft was 39 ft and 40 ft. The two drafts were used to investigate ship handling differences for varying underkeel clearance.

A New York class containership was also used in the Ship Navigation Simulator Study, Savannah Harbor Widening Project, Savannah, Georgia, performed by WES in 1987¹. The model was created by Tracor Hydronautics (Ankudinov 1986²). Its use in this study was to ensure the safety of the newly deepened channel design for the present ship traffic in the harbor.

The HANJIN class containership was used to ensure a safe and efficient channel for future harbor traffic expected to call at Savannah Harbor after the proposed project conditions were established. This model was created by BMT International, Inc. (Ankudinov 1992³). Both of these vessels were decided upon with the cooperation of the District and pilots of the area.

¹ Hewlett, Christopher J., Daggett, Larry L., and Heltzel, Samuel B. 1987(May). "Ship Navigation Simulation Study Savannah Harbor Widening Project Savannah, Georgia," Technical Report HL-87-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

² Ankudinov, Vladiir. 1986(Feb). "Hydrodynamic and Mathematical Models for Ship Maneuvering Simulation of the Containership, 'Econoship' (operated by the United States Lines, Inc.) In Full Load Condition for Deep and Shallow Waters," Technical Report 86002-1, Tracor Hydronautics, Inc., Laurel, MD; prepared for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

³ Ankudinov, Vladimir. 1992. (March). "Hydrodynamics and Mathematical models for Ship Maneuvering Simulations of the Containership 'HANJUN' in the Support of WES Savannah Harbor Deepening Study," Technical Report 9292-003, BMT International, Inc., Columbia, MD.

Description of Simulation Navigation Tests

Currently licensed Pilots from Savannah Harbor tested the main Harbor area. Testing performed in the Kings Island Turning Basin was done with licensed Docking Pilots who work in the area and normally do the docking and undocking of ships. The study tests were performed using flood and ebb spring tides for both Base and Plan conditions. Maximum navigation conditions encountered by pilots during normal operation are used in simulation tests in order to design a safe and efficient channel. Normally, this means all runs would be conducted with "fair tide"; that is, the ship transiting in the same direction as tidal currents. This is usually regarded as the least safe condition because less water is moving past the rudder reducing steerage; therefore, the ship travels faster with respect to the ground. However, the pilots felt that for Savannah Harbor "adverse" tidal conditions were more severe than the "fair" tide and was verified by preliminary test runs. Therefore, inbound runs were conducted with ebb tide and outbound runs with flood tide.

Testing was divided into two areas: Kings Island Turning Basin and the main Harbor. Tests for both were carried out simultaneously on two separate simulators. Turning basin maneuvers were conducted with the docking pilot in control of the ship's rudder and engine controls, and giving commands for tug assistance. Up to five tugs were available at all times during maneuvering, a normal situation for the pilots. However, most maneuvering in the turning basin during simulation testing required the use of only three tugs. Main harbor maneuvering was performed with the river pilot giving rudder and engine commands to a helmsman, as in normal operation. When testing first began, turning basin maneuvers took a maximum time of 30 minutes to complete because the pilot started from Marsh Island Turning Basin, maneuvered up to Kings Island Turning Basin and performed the turn. However, it was discovered that the pilot could set up for the turn as close as 4 to 5 ship lengths downstream of Kings Island Turning Basin. When the ship's initial placement was changed to reflect this, the maneuvering times dropped to 15 to 20 minutes allowing more testing. The main harbor tests took approximately 2 hours to complete, depending on whether it was inbound or outbound, so a maximum of four tests could be completed in a day. With normal operational problems, this number was reduced to an average 3 runs a day.

Results of the Simulation Navigation Model

Plates 25-44 show pilot tracklines for the Base and Plan conditions tests, inbound ebb tide, and outbound flood tide ship transits. Plate 45 shows reference points for the graphs in Plates 46 and 47 of rudder commands, and port and starboard clearance. The five inset groups have been placed together to make it easier to see similarities in the tracklines of the ships. Since only the depth of the channel has changed between the Base and Plan conditions, the

pilot's general approach to maneuvering stays the same. Results will be discussed starting from Kings Island Turning Basin and going downstream.

As can be seen from Plates 25-28, the docking pilots do not experience any more difficulty in the Plan conditions while turning the ship around than the Base conditions within the Kings Island Turning Basin. However, the river pilots have difficulty during ship transits in both the Base and Plan conditions at the lower section of the Marsh Island Turning Basin. There was a consistent encroachment upon the southeastern corner of Marsh Island Turning Basin during outbound flood conditions for both the Base and Plan conditions (Plates 26 and 28). The maximum encroachment for the Base condition was 46 ft, and for the Plan 56 ft. This difficulty concurs with the conclusions of the 1987 WES study and is partially due to the placement of the Amoco dock and compounded by the orientation of the currents in the area.

Inset 2 (Plates 29-32) shows the Highway 17A Bridge and the Hyatt Hotel area. As can be seen from these figures, the pilots had difficulty maneuvering for both the Base and Plan conditions in this area. The areas of encroachment moved somewhat upstream for the inbound runs between the Base and Plan conditions, and downstream for the outbound runs of both conditions. However, when creating the figures for this report, a discrepancy was discovered in the bank line position, seen in Inset 2 figures, where the channel line crosses the bank line. This occurred because the aerial photographs used for the visual scene were taken in November 1988, before the widening of the channel.

Since the pilots navigate through this area without the use of buoys to mark the edge of the channel, the bank line is very important in determining the ship's position in the channel. After receiving new survey sheets from the District and comparing the bank line position to the visual scene bank line, an average 200 ft difference in the placement of the bank line was seen in this area (Plate 48). Plates 46 and 47 show significant use of the rudder just upstream of Fig Island Turning Basin and just downstream of the Highway 17A Bridge; however, the total change in heading in this area is almost 60 deg so this was not unexpected. Also, the rudder was not constant, occurring only at the beginning and end of this inset, so the ship was capable of some additional maneuvering. The encroachment by the pilots on the southern channel line averages less than 100 ft but two pilots expressed a concern that the ship was turning too slow. These combined factors suggested that the pilots would be able to navigate the area between the Highway 17A Bridge and Fig Island Turning Basin with little or no more difficulty than existing operations in the area. Additional testing with the corrected bankline would confirm this evaluation.

The next concern was the Fort Jackson area (Plates 33-36). The pilots experienced no loss of maneuverability in this area. Outbound runs in the Plan condition (Plate 36) did approach the channel edge nearest the wreck of the CSS Georgia; however, the minimum clearance was approximately 50 ft abeam of the site and should not pose a problem. Although Plate 47 shows significant rudder angles before and after the Fort Jackson area (point C), the rudder was not

maintained throughout that area. This, plus the fact that almost every pilot maneuvered toward the wreck, suggested that the trackline showed the approach pilots are accustomed to using in this area. Although currents in the flood tide tend to be oriented toward the wreck site, the lack of significant rudder use in this area showed that the magnitude of the current does not appear to effect ship maneuverability to any great degree.

The bight, or bend, shown partially in Inset 3 (Plates 33-36) and mostly in Inset 4 (Plates 37-40) is apparently the most difficult maneuver in the harbor. Plates 46 and 47 show that the rudder given in this area (between points B and C) was at least 20 deg (most go to 30 deg or above) and were held for the duration of the turn in almost every existing and design condition case. These rudder angles indicated the pilots were maneuvering at or near the maximum turning capacity of the ship. Even with these rudder angles the tracklines encroach upon the northern channel line by a maximum of approximately 200 ft. The pilots indicated that the bank forces in this area were used to make the turn; therefore, the ships were outside the marked channel indicating the channel was "widened" or reoriented. The most probable cause of this was the vessel traffic itself.

Just downstream of the bight area is the Atlantic Intracoastal Waterway (AIWW). The S-turn at this part of the harbor and the region around the LNG Terminal were a concern to the pilots during testing and also during discussions with them before testing. Cross currents in this region make the S-turn even more difficult to maneuver. Plates 37-44 show the trackplots for this region. Some of the encroachment along the southern part of Elba Island can be attributed to the fact that the pilots know that deep water exists in that area and make use of it. However, the deeper drafts in the Plan condition will make this area even more difficult to maneuver, seen in Plates 43 and 44. The average encroachment in this area was approximately 100 ft. The tracklines through the bend downstream of AIWW show that pilots tend to run to the outside (or northern side) of that turn.

4 Conclusions of the Navigation Model

Conclusions

The results of the Savannah Harbor Deepening Study provide these following conclusions:

- a. The impact of the deepening upon maneuvering in the Kings Island Turning Basin was minimal, and the docking pilots were satisfied with the results after the previously mentioned changes were made to the currents in the basin. This made them more representative of the observed local variations.
- b. The lower portion of the Marsh Island Turning Basin becomes even more of a problem for the Plan condition. This portion of the channel needs modification so the pilots will not have to travel too close to the Amoco dock.
- c. Problems occurring near the Highway 17A Bridge can be attributed partially to the erroneous bank line configuration used in the visual scene. The difference in the encroachment between the Base and Plan conditions was less than 40 ft in most cases. With the widening already in place the pilots should be able to keep the ship away from the southern channel edge.
- d. The width of the deepened channel in the Plan conditions at the Fort Jackson/CSS Georgia wreck site should not pose any problems for the pilots.
- e. The existing navigation problem with maneuverability in the bight region of the harbor, upstream of the LNG Terminal, will increase with the Plan conditions. Pilots are already maneuvering close to the limit of the ship's ability in this area and typically operate outside the authorized channel in deep water. However, this area outside the

channel will not accommodate the deeper draft vessels in the Plan conditions.

- f. The navigation problem at the S-turn in the area of the AIWW will also increase. The pilots have expressed a concern over the space provided in this bend. The increased momentum of a ship with an extra 2- to 4-ft draft will cause the width in this bend to be critical.
- g. The inside (southern side) of the bend just downstream of AIWW is not used for maneuvering by the vessel traffic in the channel.

Recommendations

Based on these conclusions the following recommendations are proposed for your consideration:

- a. The lower southeastern corner of Marsh Island Turning Basin, shown on Plate 49, should be widened by 75 to 100 ft to allow pilots a safe distance to maneuver around ships moored at Amoco Dock.
- b. The bight upstream of the LNG Terminal, Plate 50, should be widened from 600 to 800 ft. This should give the pilots adequate room to maneuver the deeper draft vessels around this bend.
- c. As shown in Plate 50, the S-turn at AIWW should be widened because the extra space in the channel would allow pilots to maneuver safely through the turn. However, the widening in the bend downstream of the AIWW can be decreased by 100 ft, as shown in Plate 50, because the pilots generally do not use that area.

Plates 51-60 show a closer look at the river bight area and the widening modifications shown in Plate 50. In these figures, the 38 ft and 36 ft contour lines, with respect to mean low water, have been plotted against the existing channel (Plates 51-54 show the 36-ft contour, and Plates 55-56 show the 38-ft contour). These plots show, for the majority of the bight area, both contours fall outside the channel line. Since the pilots bring a maximum of 36 ft draft ships through this region, these plots show a tendency for the pilots to use this region outside the channel because the bank forces help maneuver the ship around the turn. In Plates 57-59, the tracklines of all the pilot runs fall inside the 36 ft contour line except one or two cases. Plate 60 shows the modified channel in the bight region (from Plate 50) in relation to the 36 ft contour. Since this depth is with respect to mean low water, a tide of just one to two ft would give ample underkeel clearance for maneuvering a 36 ft draft ship in this area. This figure also shows that the modified channel lies almost directly on top of the 36 ft contour line.

Further Developments

After the simulation tests were completed and the recommended channel design was sent to the Savannah District, several logistic problems in the Marsh Island Turning Basin area were discussed. The District asked WES (July 1992) to review a proposed realignment of the channel in the area, see Plate 61, and determine any adverse effects. Analysis of the realignment showed the southeastern edge of the realignment did not affect navigation, see Plate 62; however, the western side of the channel caused encroachment up to 70 ft, see Plate 63. WES proposed two possible solutions for that area, see Plates 64 and 65. Plate 64 shows a 50-ft realignment on the western side of the channel by Union Camp Corporation; this option requires further testing. Plate 65 shows a realignment from the turning basin notch all the way down to the bend apex in front of Union Camp Corporation. This realignment requires no further testing since it accommodated current pilot practice in the area. WES recommended the modification shown in Plate 65.

Further talks with the Savannah District revealed that the northern line of the modified channel in the area of Station 51+350, see Plate 66, interfered with an existing Southern Natural Gas Company pipeline. Dredging in this area would have meant moving the existing pipeline at great expense. WES was asked to review a realignment for that specific area. A direct placement of tracklines from the pilots' testing showed very little infringement upon the District proposed realignment, see Plate 67. Further investigation showed the rudder settings for maneuvering in this reach were nominal and that the realignment should not greatly affect the vessel's maneuverability. WES concurred with the Savannah District's proposed realignment at Station 51+530.

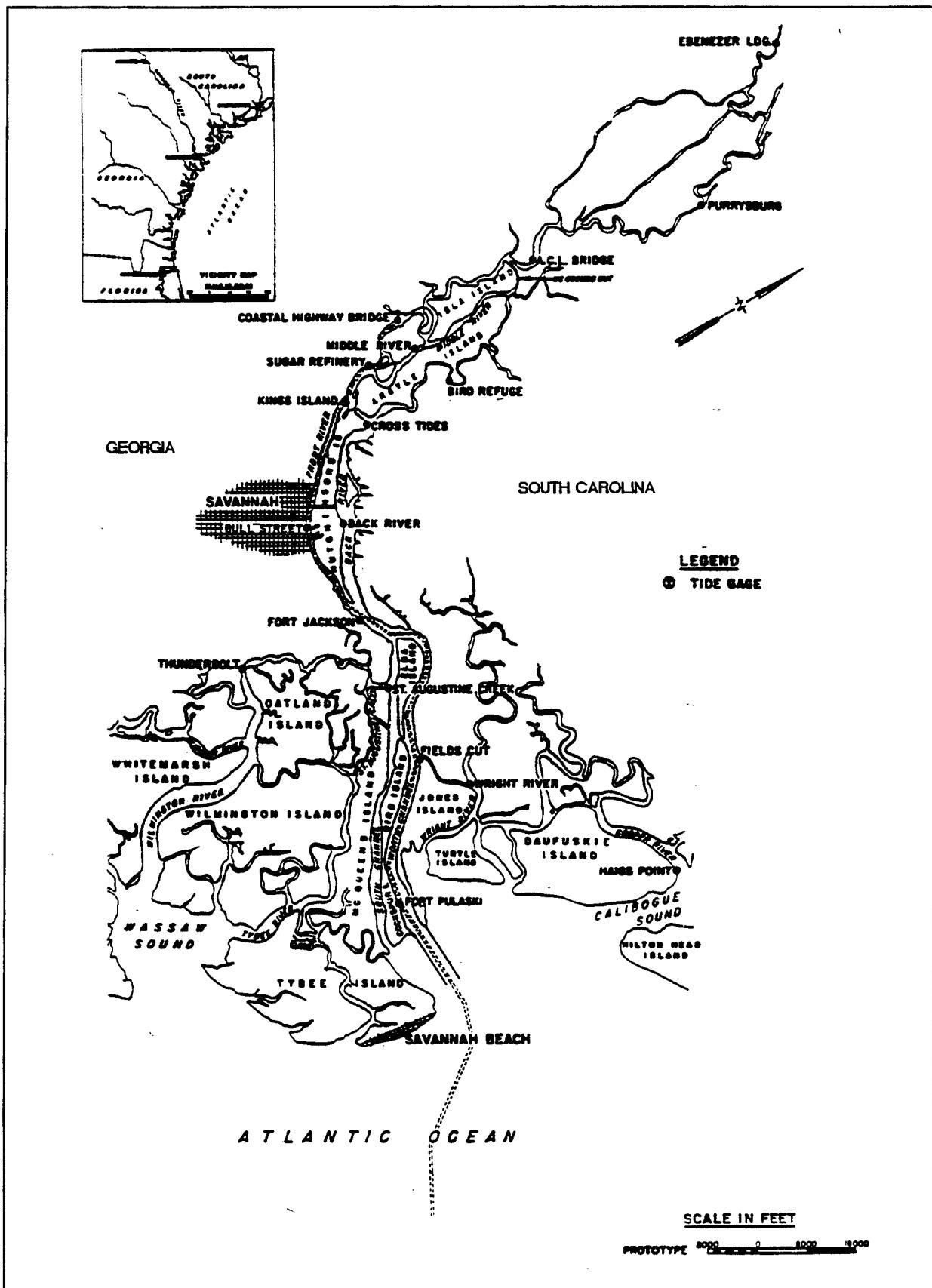


Figure 1. Savannah Estuary site map

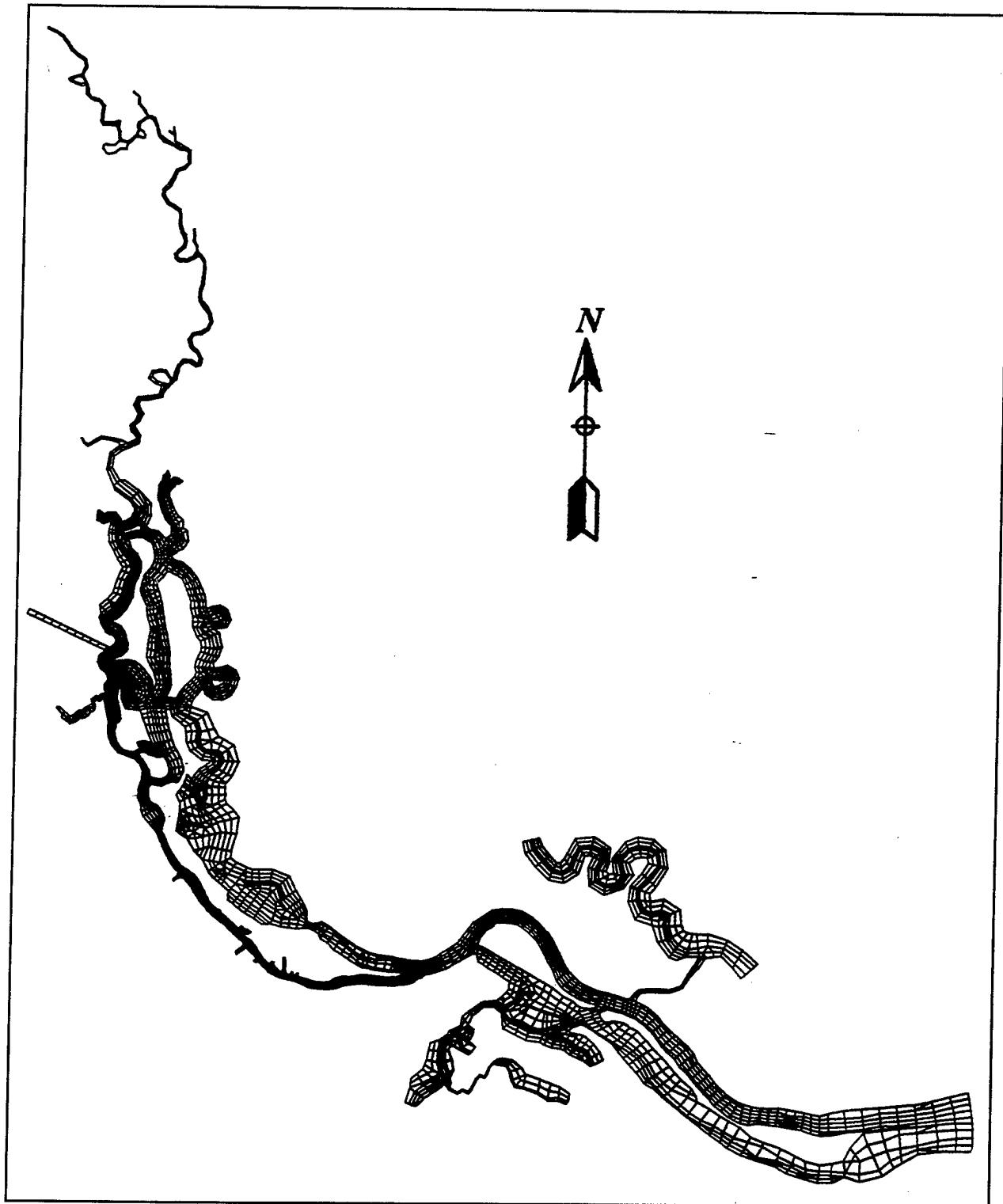


Figure 2. Savannah River and Estuary finite element mesh

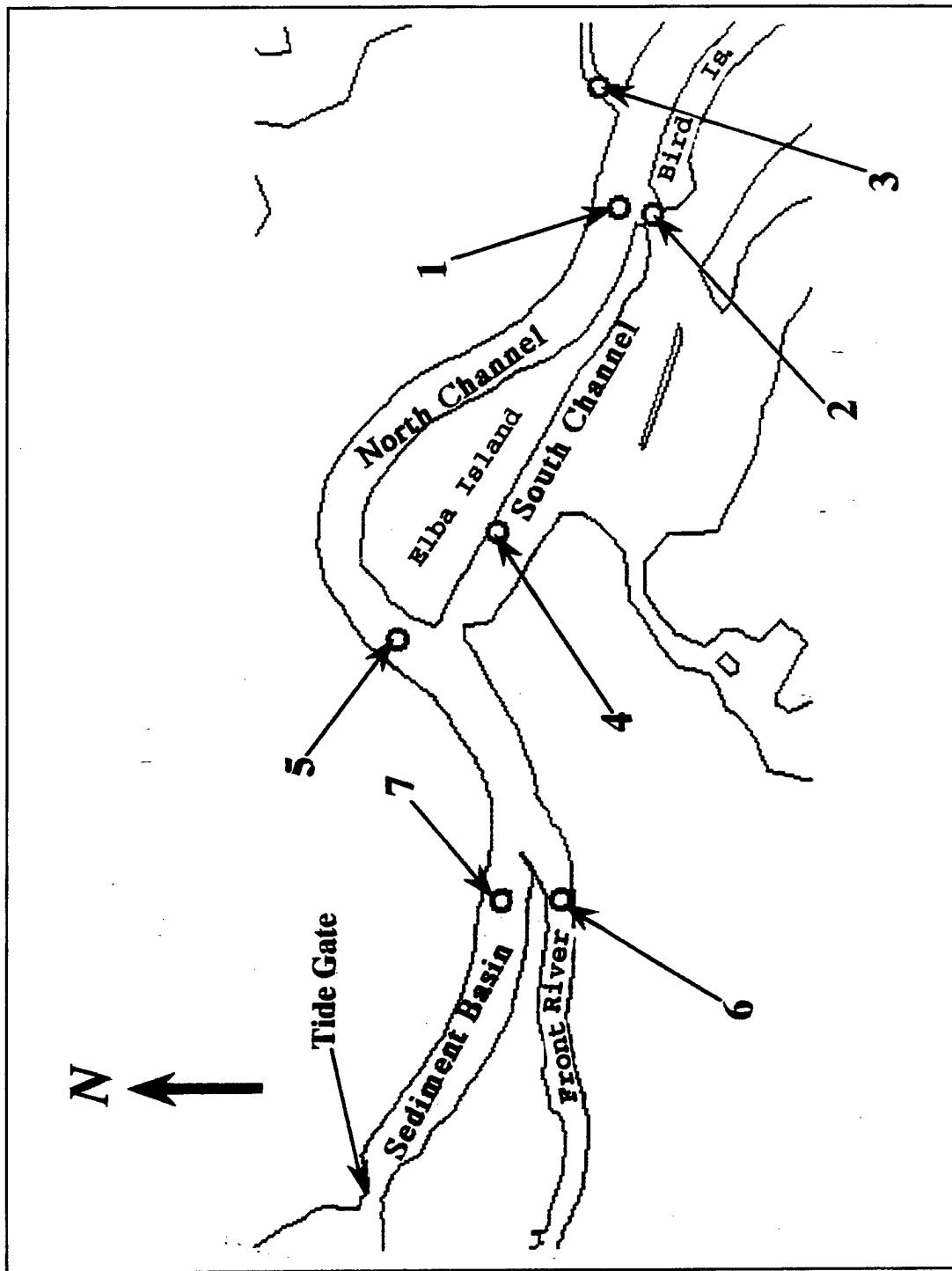


Figure 3. Savannah River stations, 30 October 1991

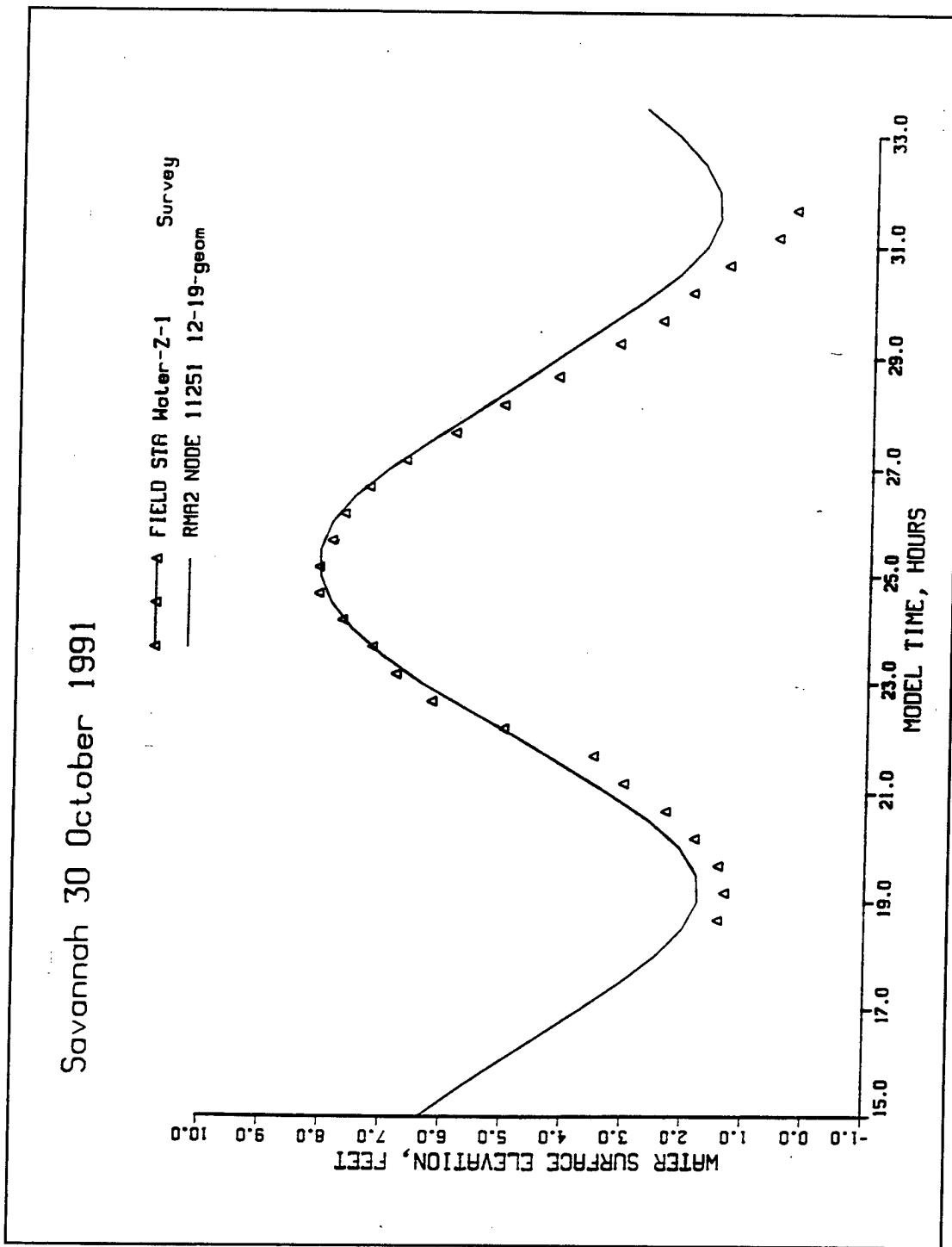


Figure 4. Comparison of field data and numerical model results at station 1

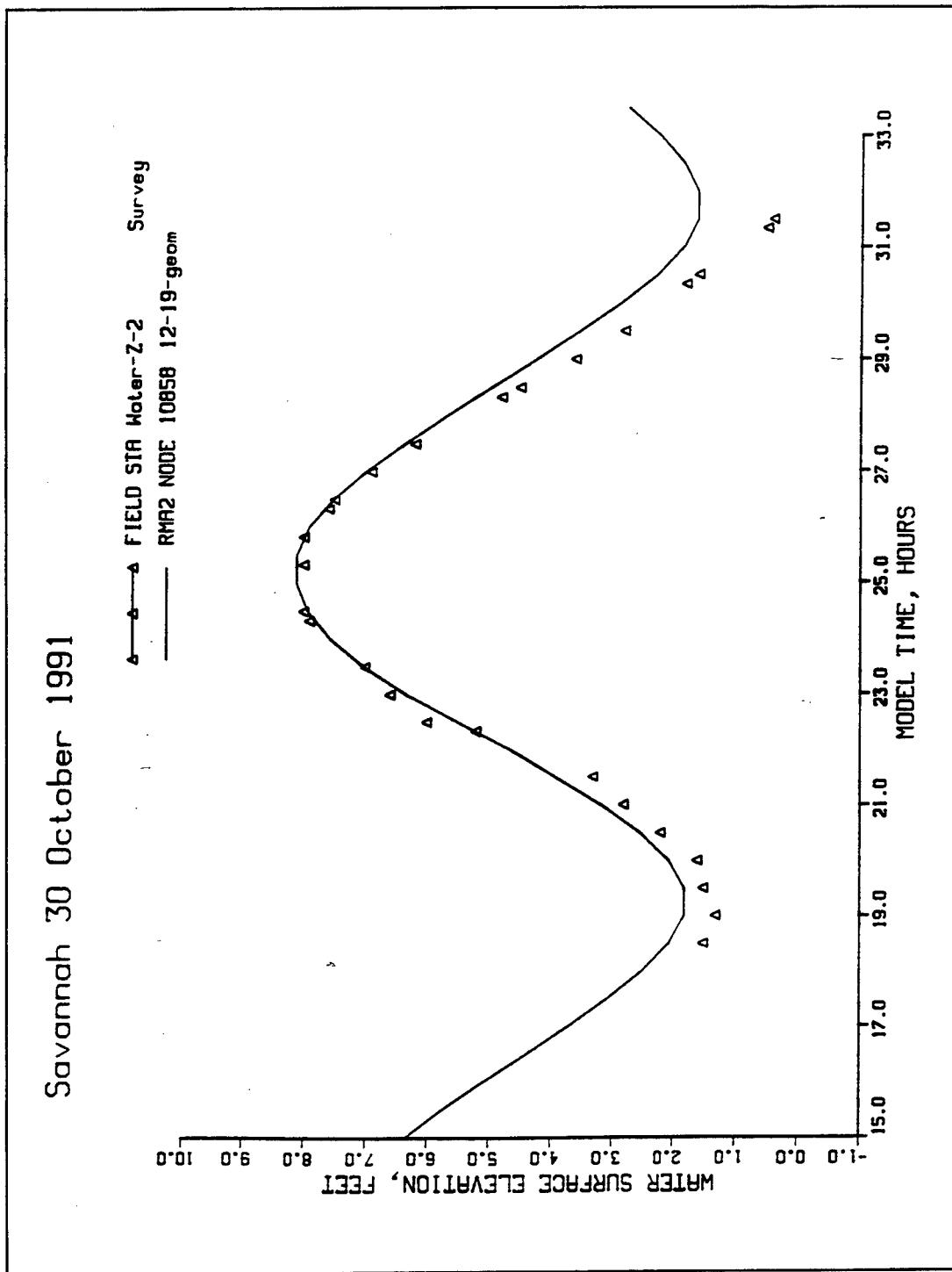


Figure 5. Comparison of field data and numerical model results at station 2

Savannah 30 October 1991

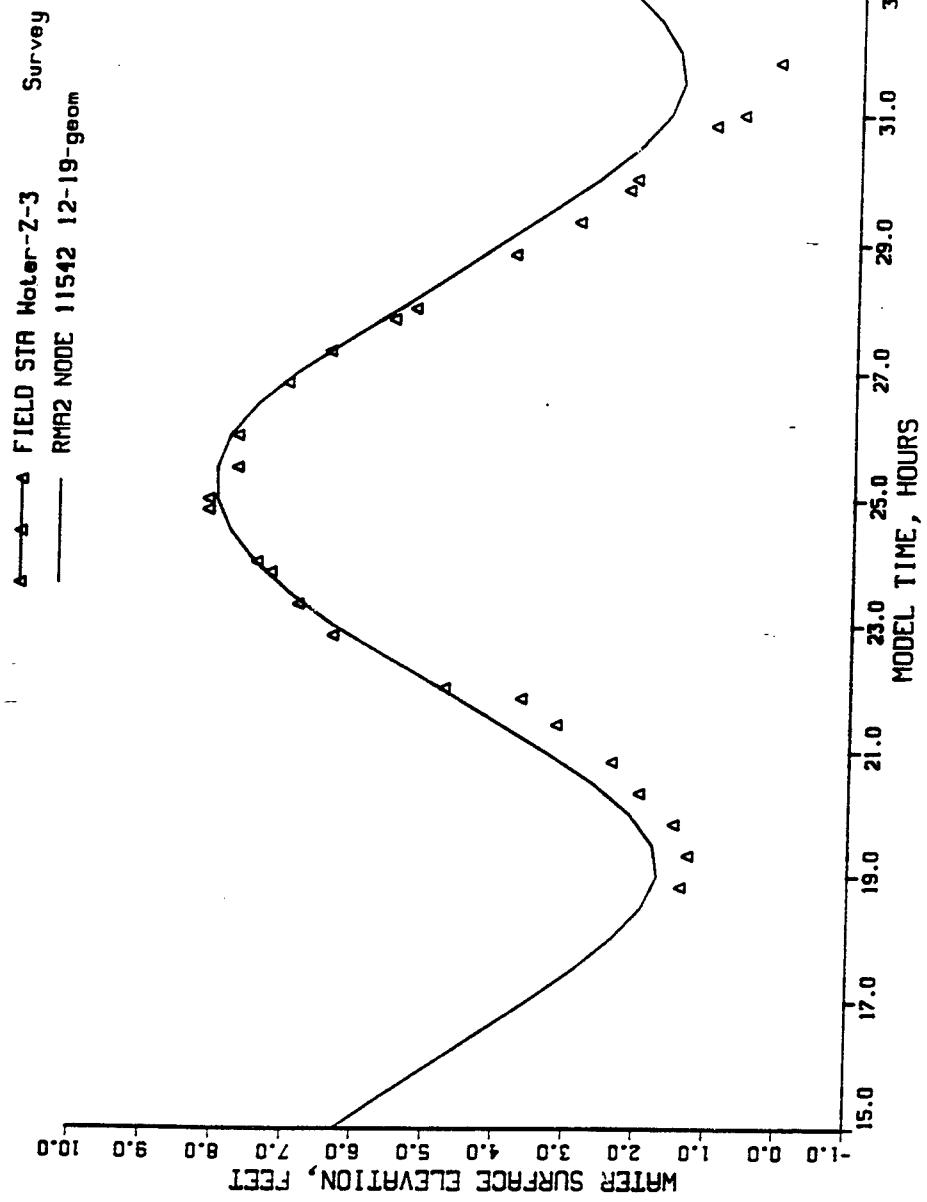


Figure 6. Comparison of field data and numerical model results at station 3

Savannah 30 October 1991

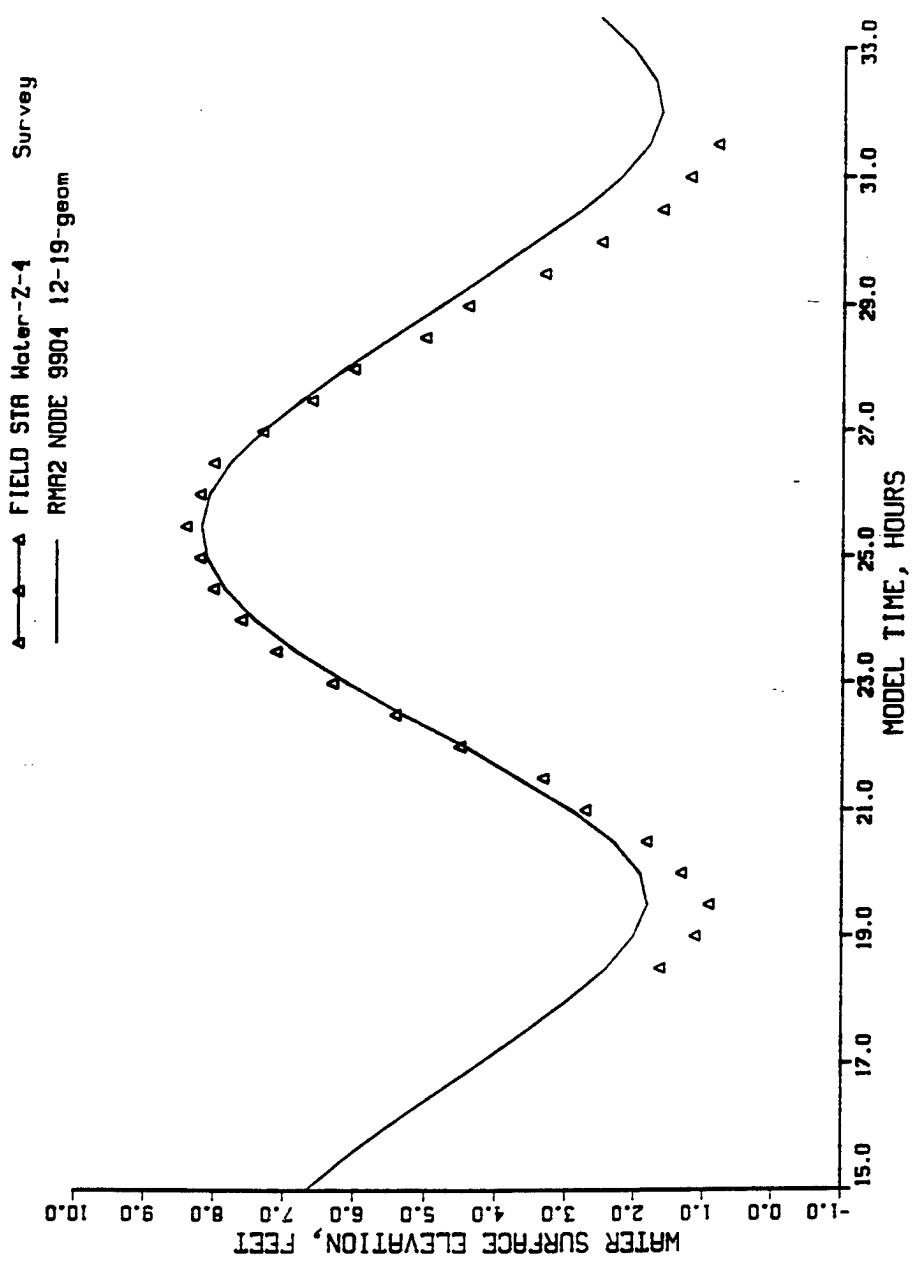


Figure 7. Comparison of field data and numerical model results at station 4

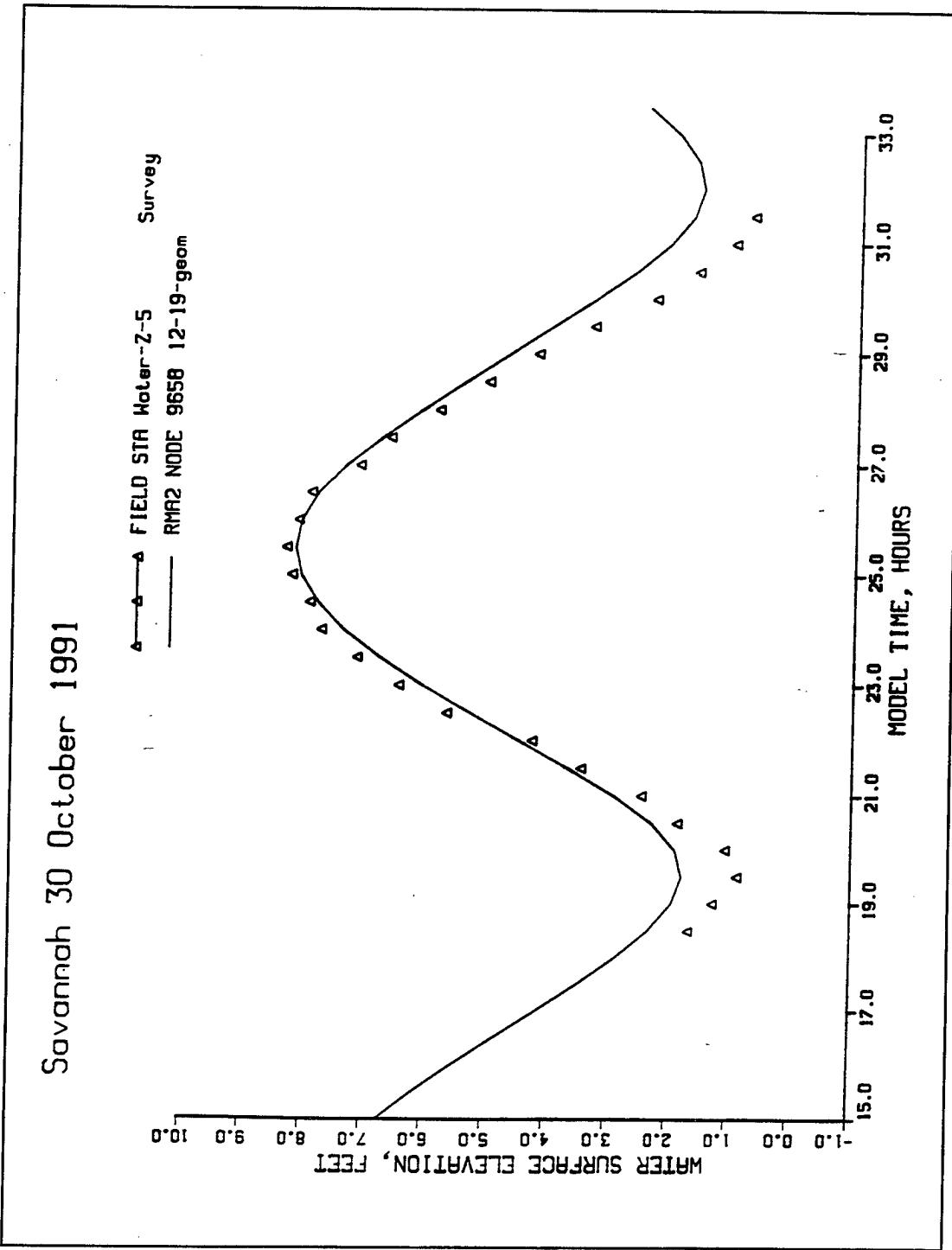


Figure 8. Comparison of field data and numerical model results at station 5

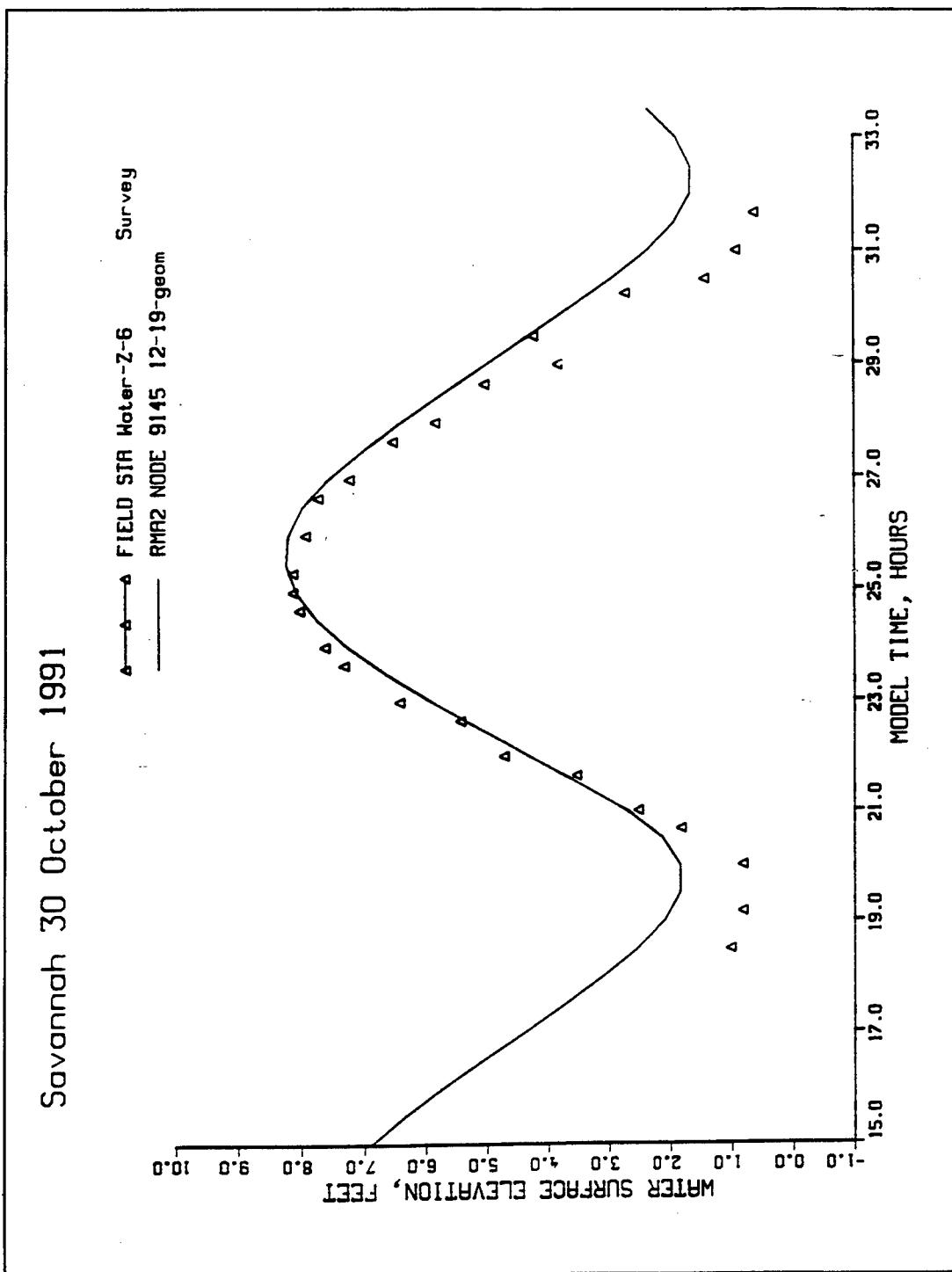


Figure 9. Comparison of field data and numerical model results at station 6

Savannah 30 October 1991

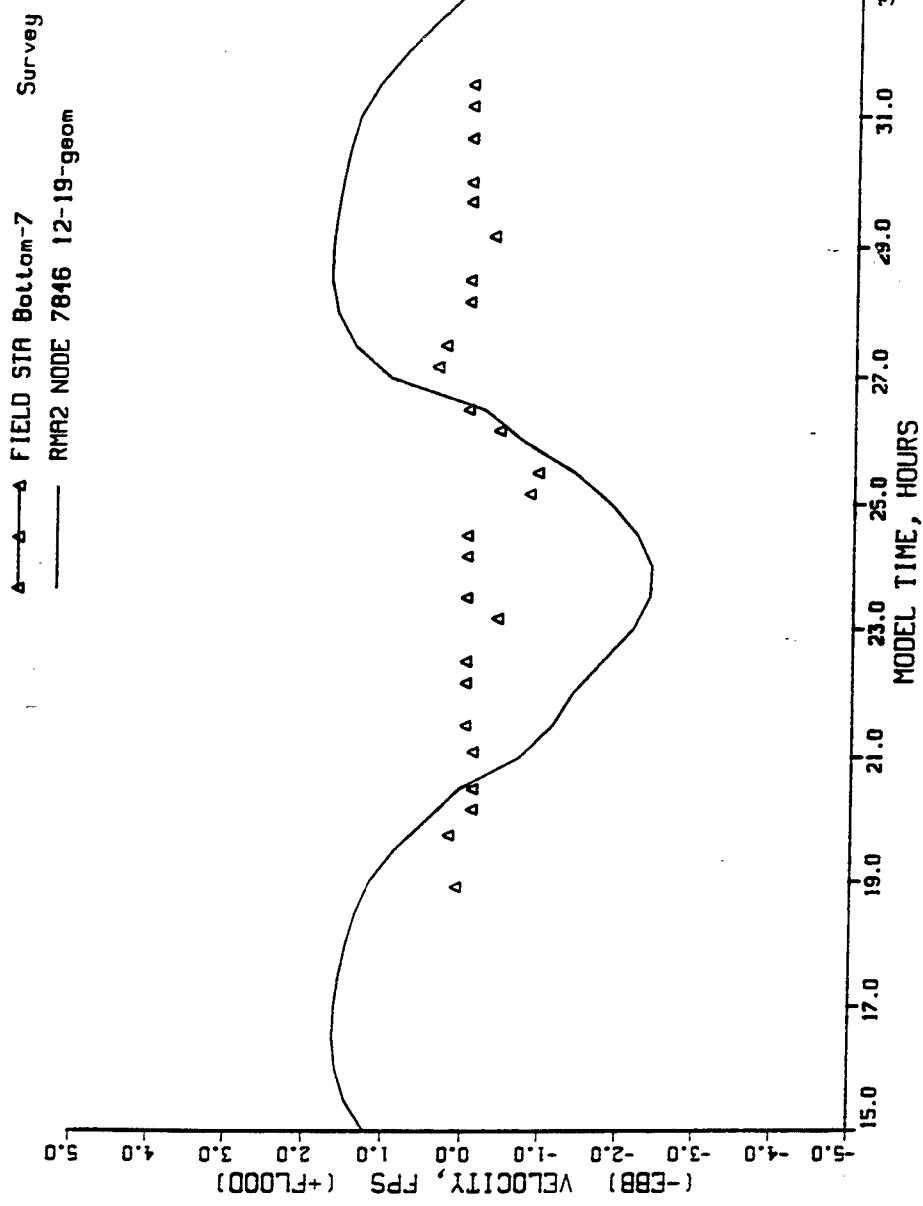
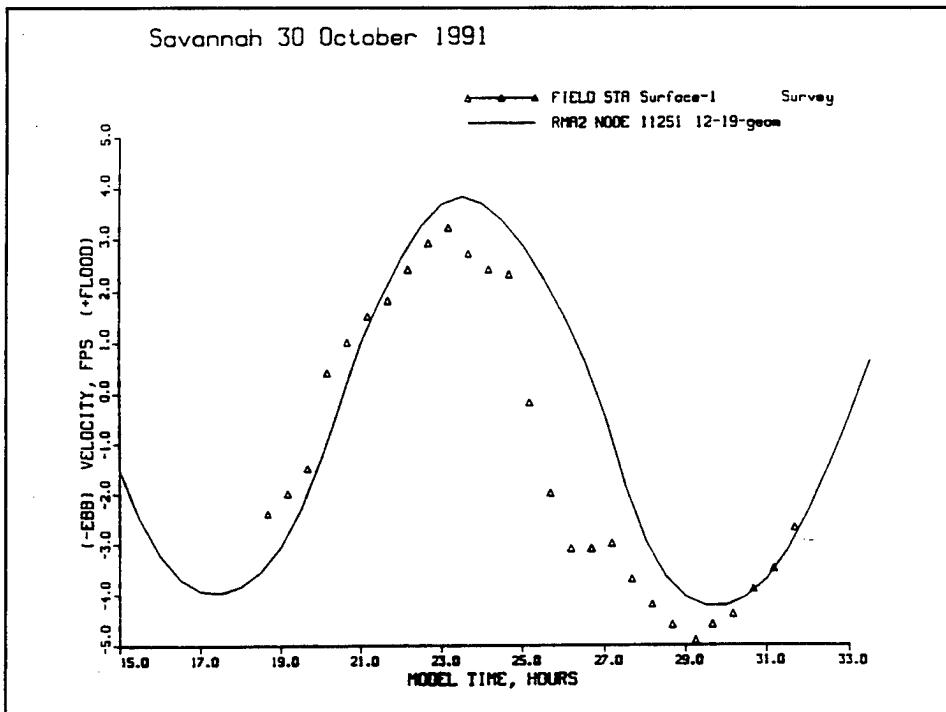
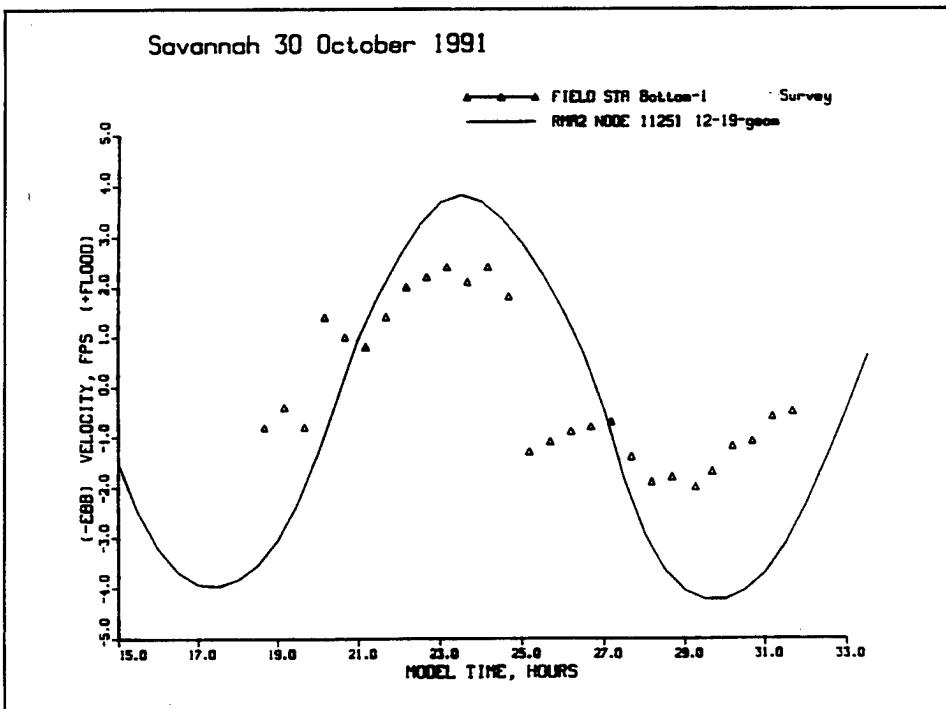


Figure 10. Comparison of field data and numerical model results at station 7

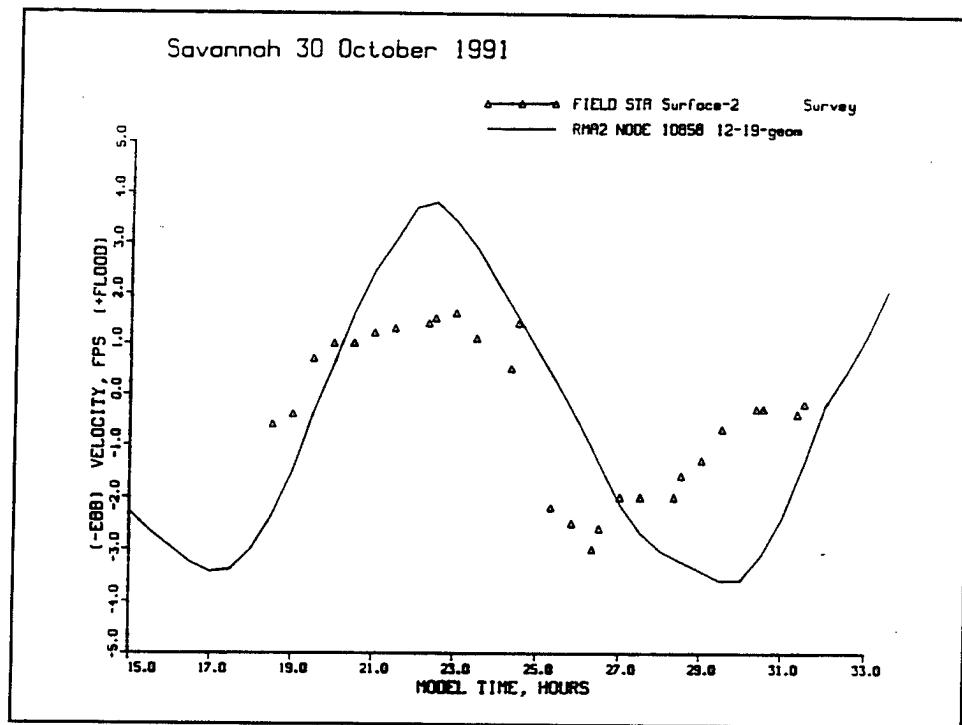


a. Surface

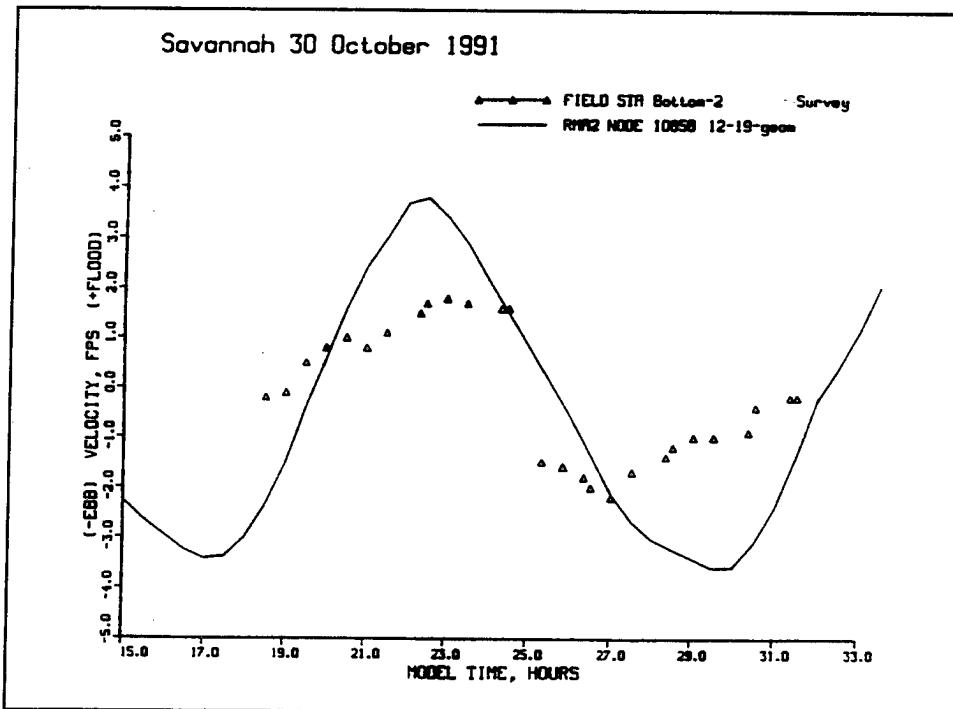


b. Bottom

Figure 11. Comparison of field data and numerical model results at station 1

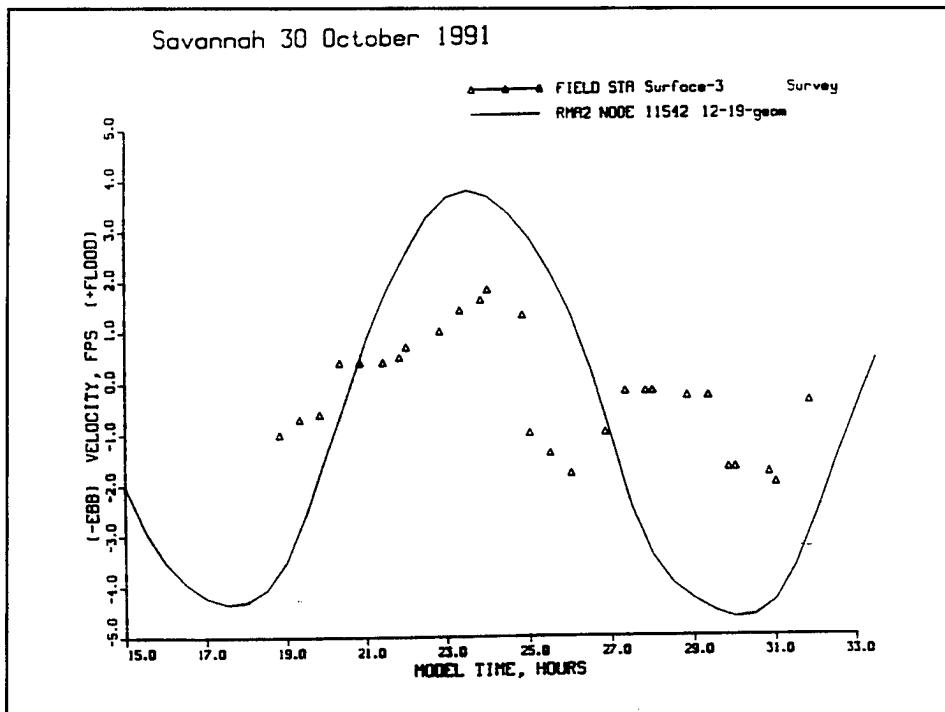


a. Surface

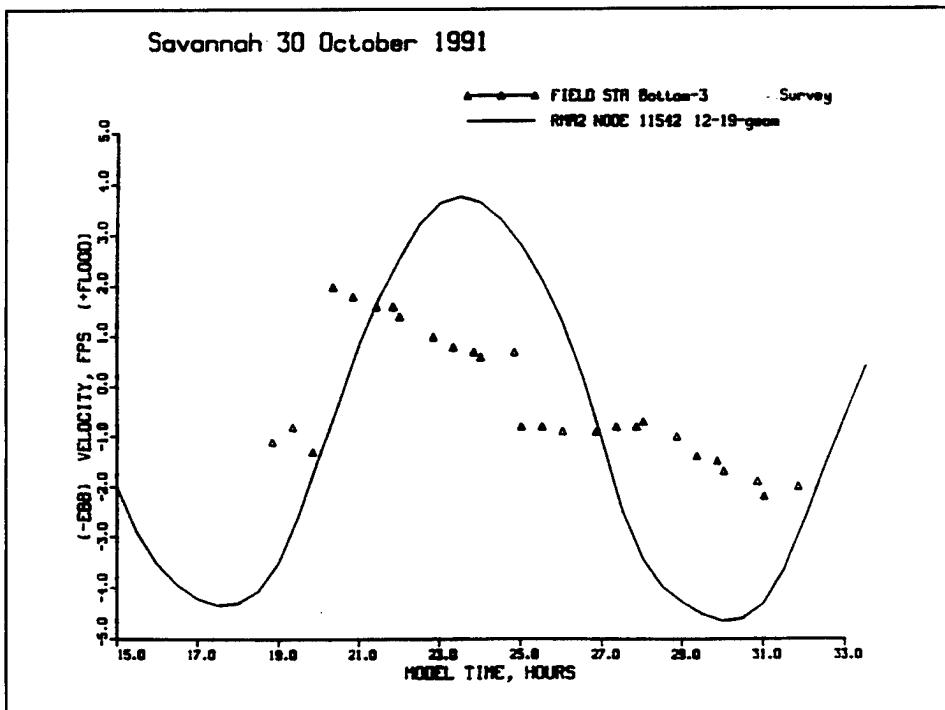


b. Bottom

Figure 12. Comparison of field data and numerical model results at station 2

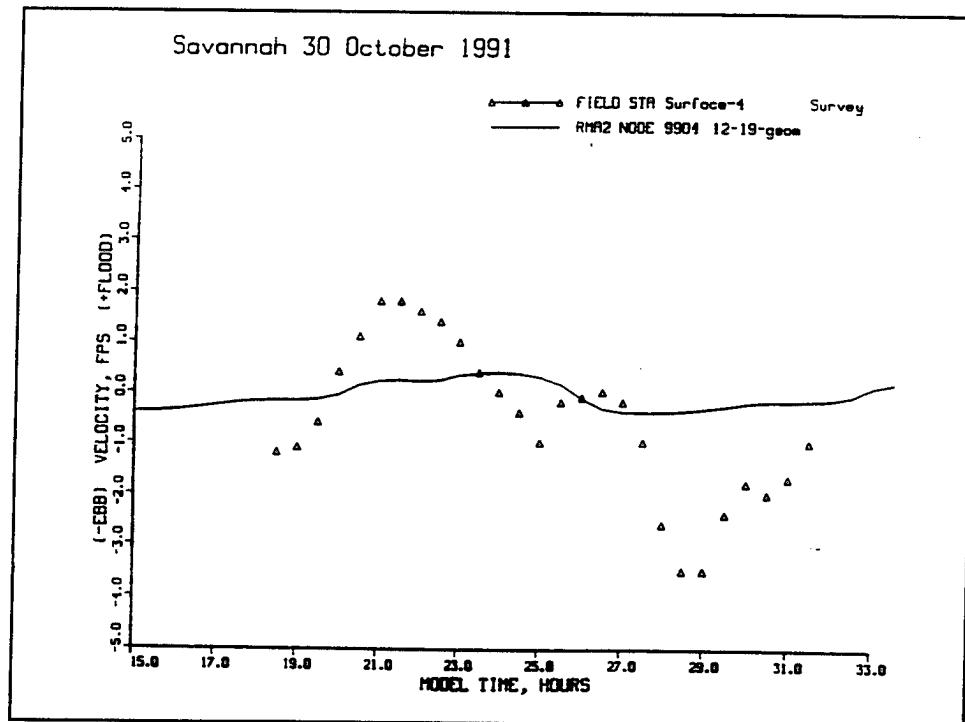


a. Surface

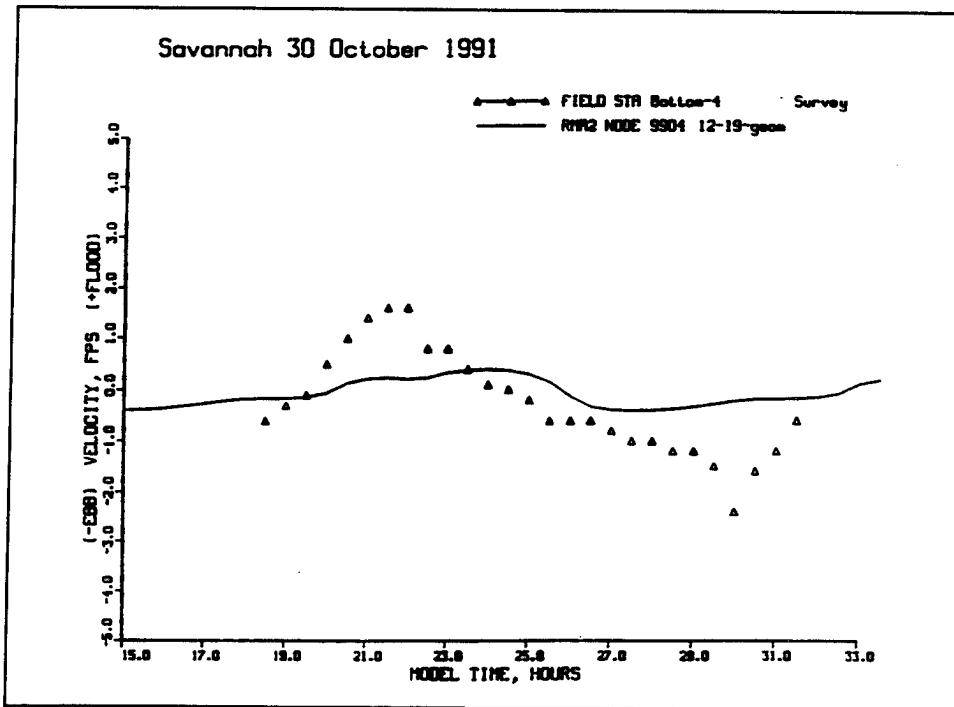


b. Bottom

Figure 13. Comparison of field data and numerical model results at station 3

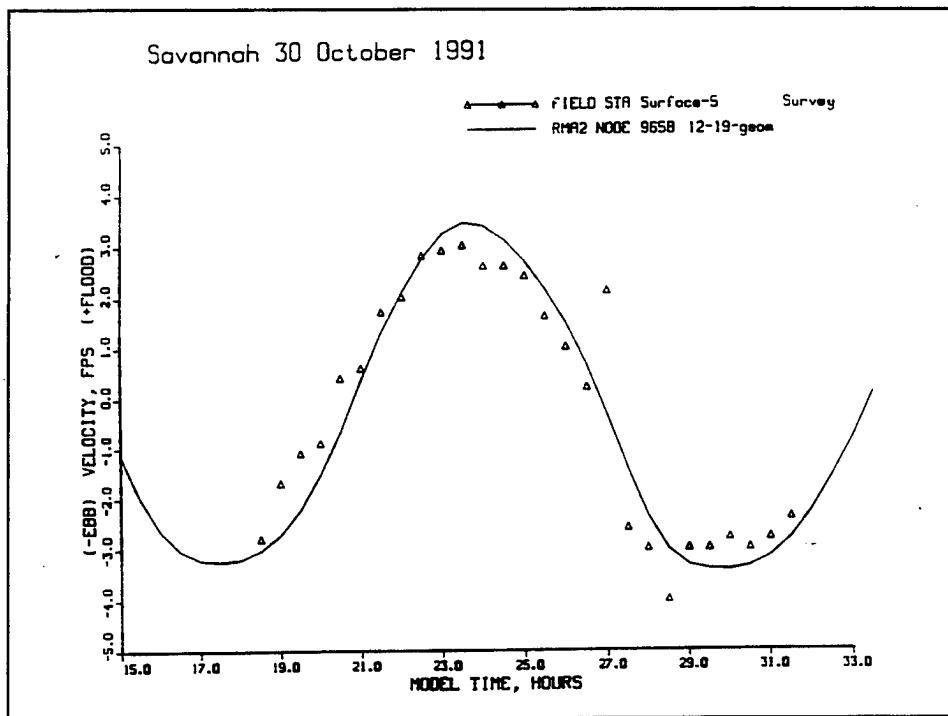


a. Surface

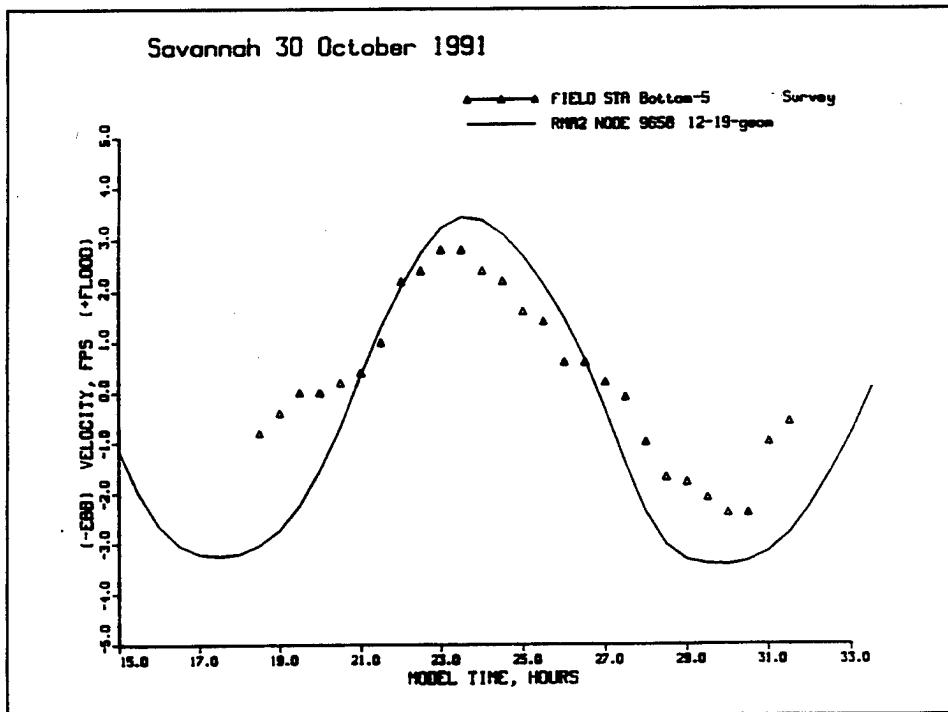


b. Bottom

Figure 14. Comparison of field data and numerical model results at station 4

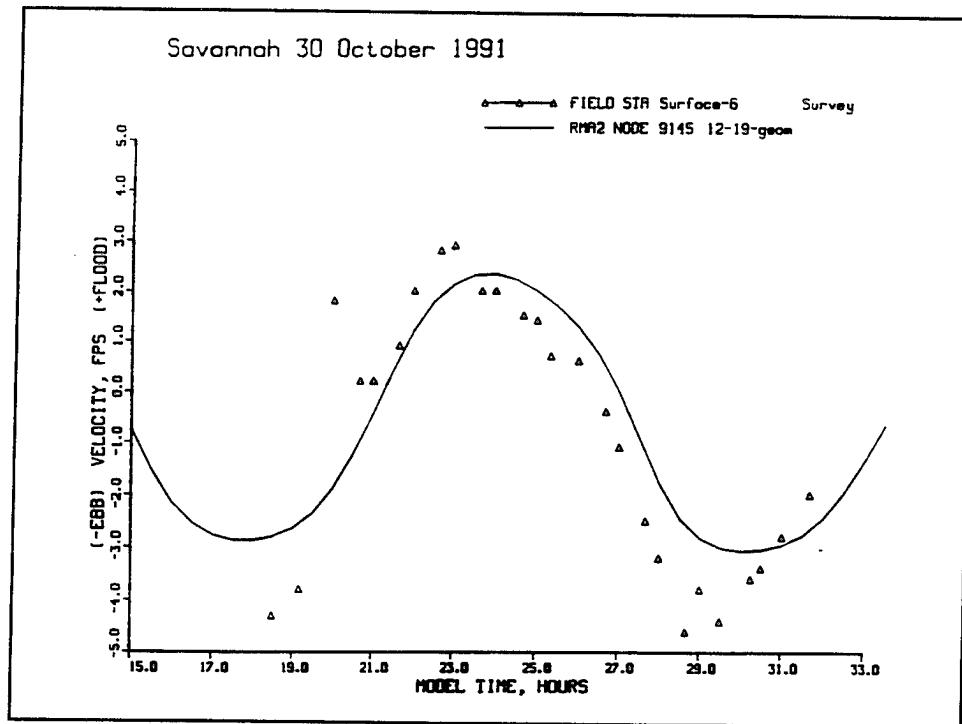


a. Surface

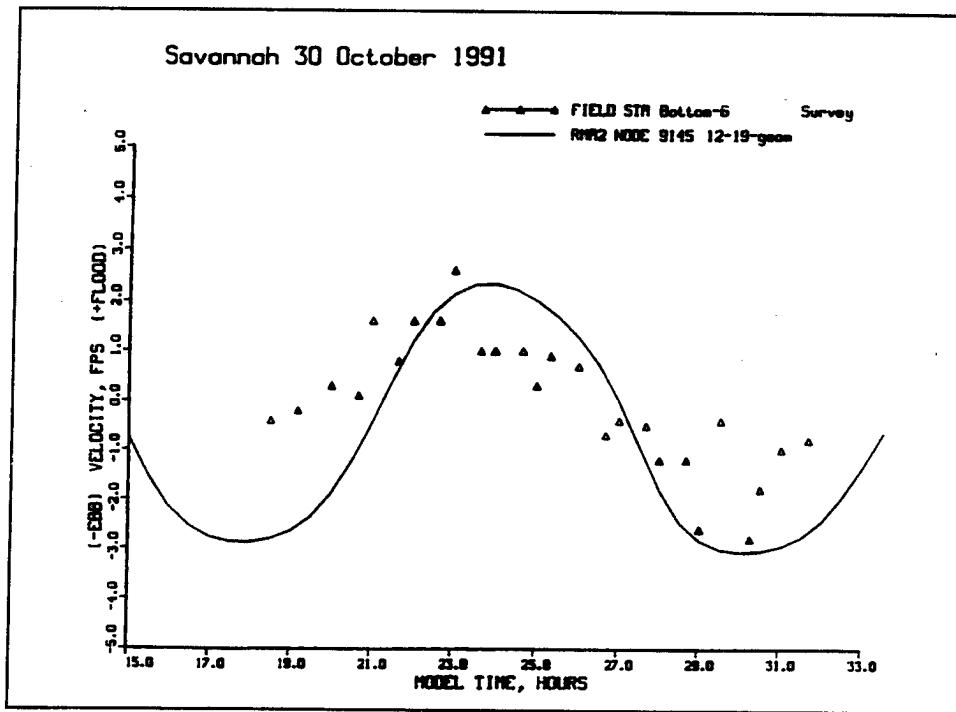


b. Bottom

Figure 15. Comparison of field data and numerical model results at station 5

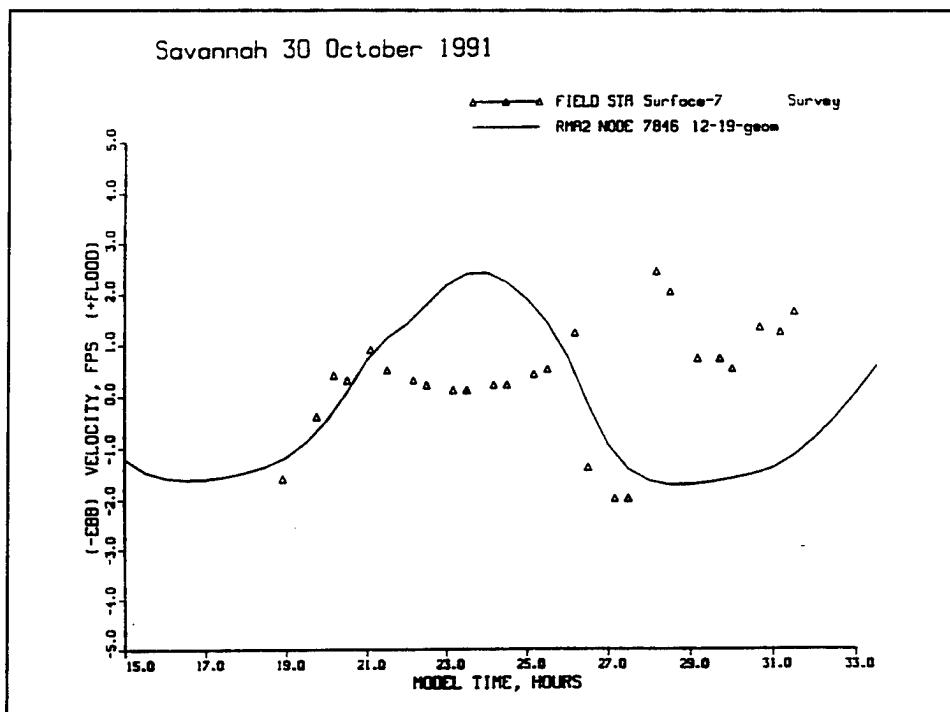


a. Surface

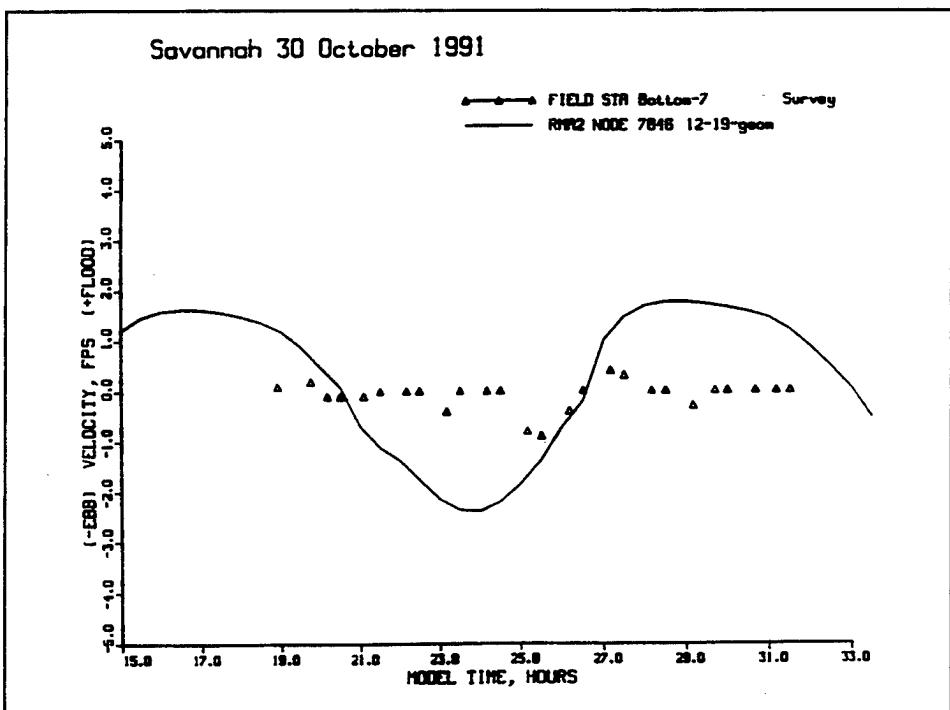


b. Bottom

Figure 16. Comparison of field data and numerical model results at station 6

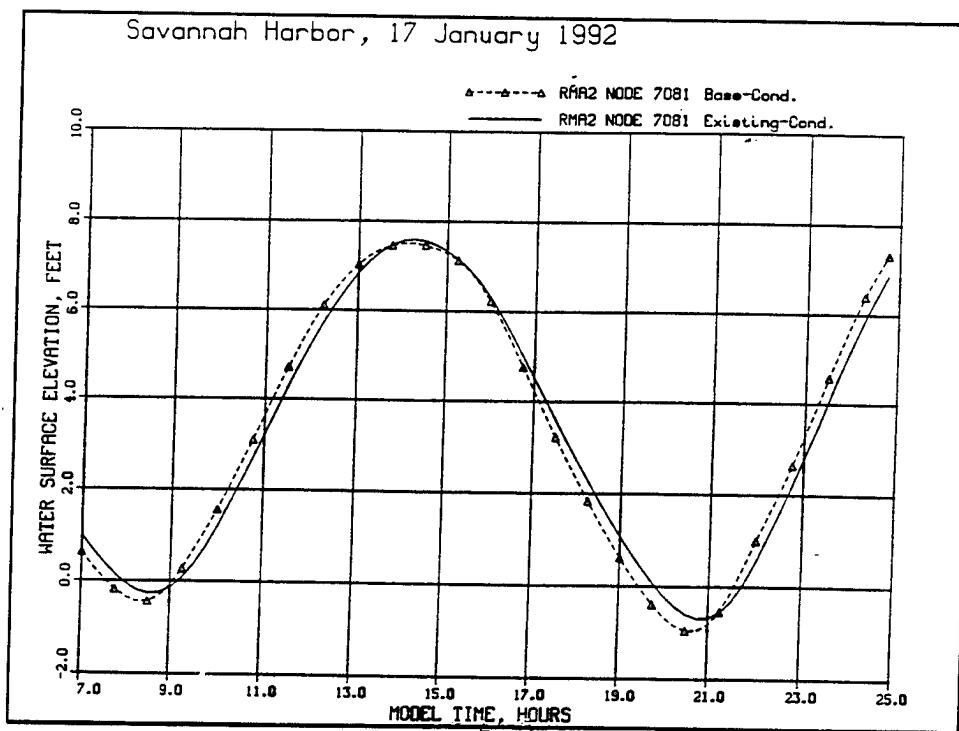


a. Surface

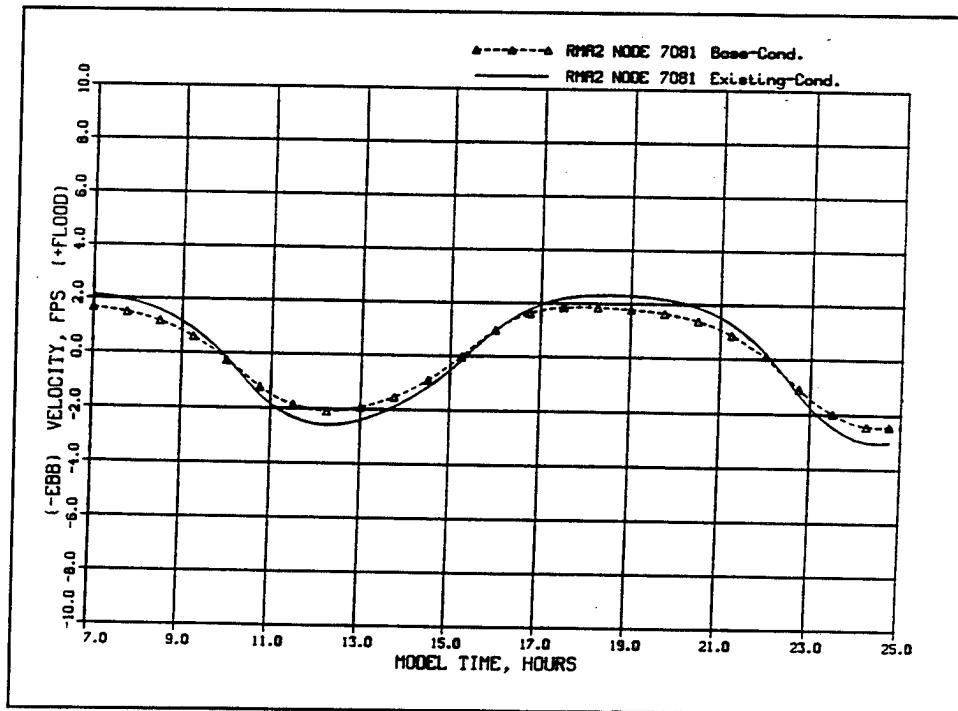


b. Bottom

Figure 17. Comparison of field data and numerical model results at station 7

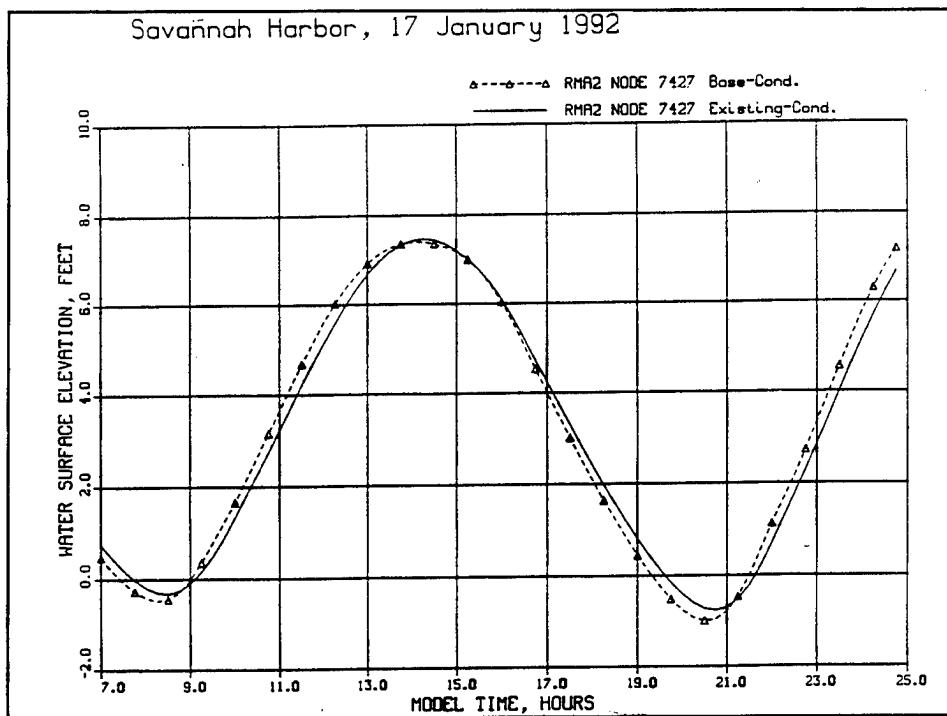


a. Water surface elevation

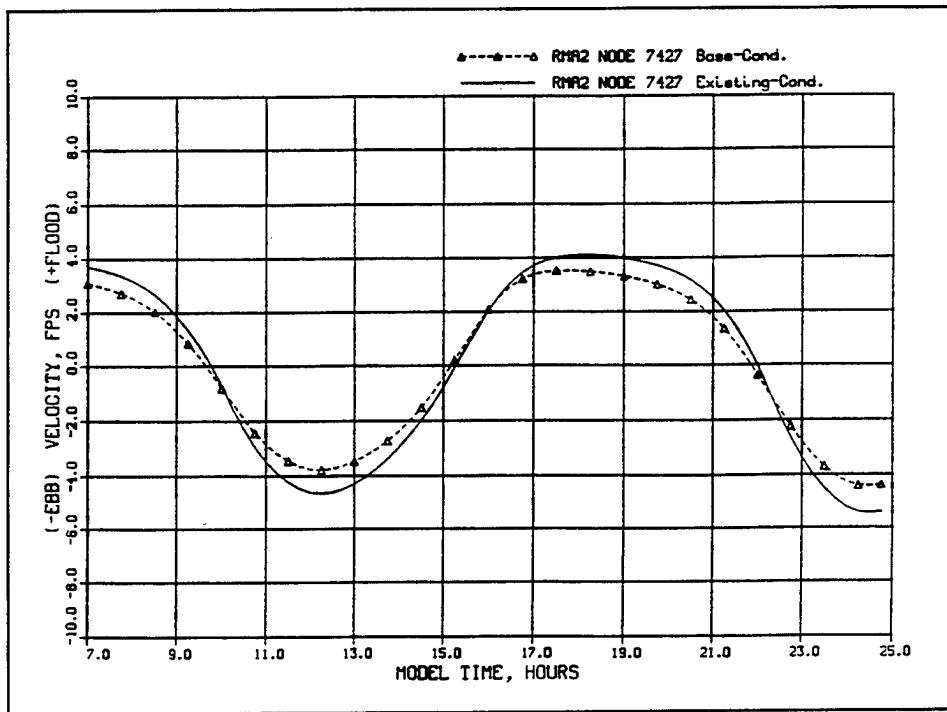


b. Velocity

Figure 18. Comparison of existing and base conditions of numerical results at river mile 18.75



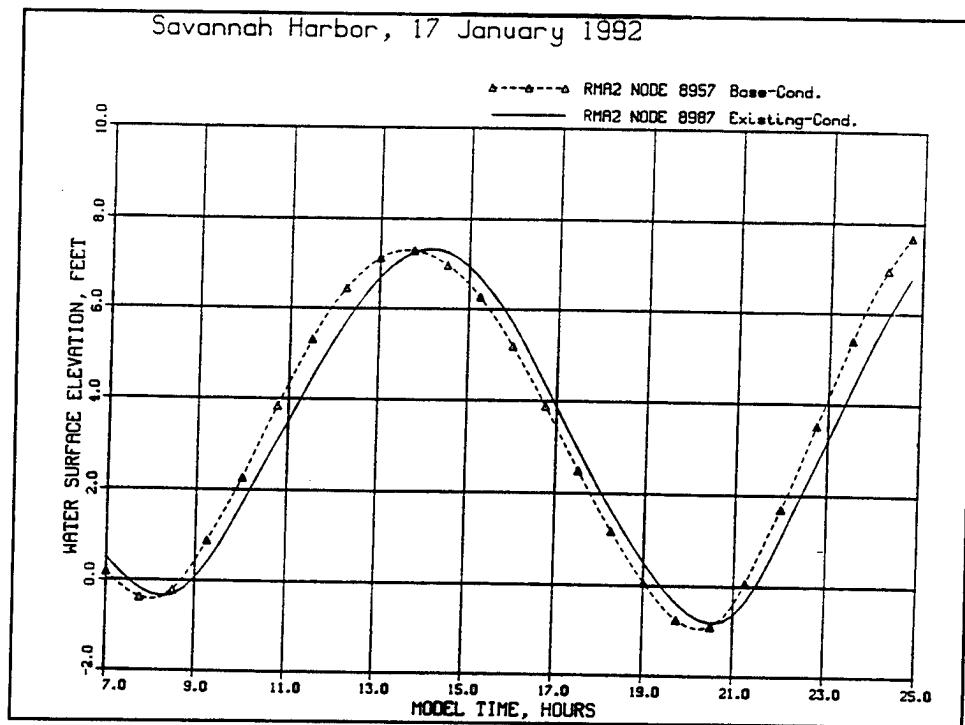
a. Water surface elevation



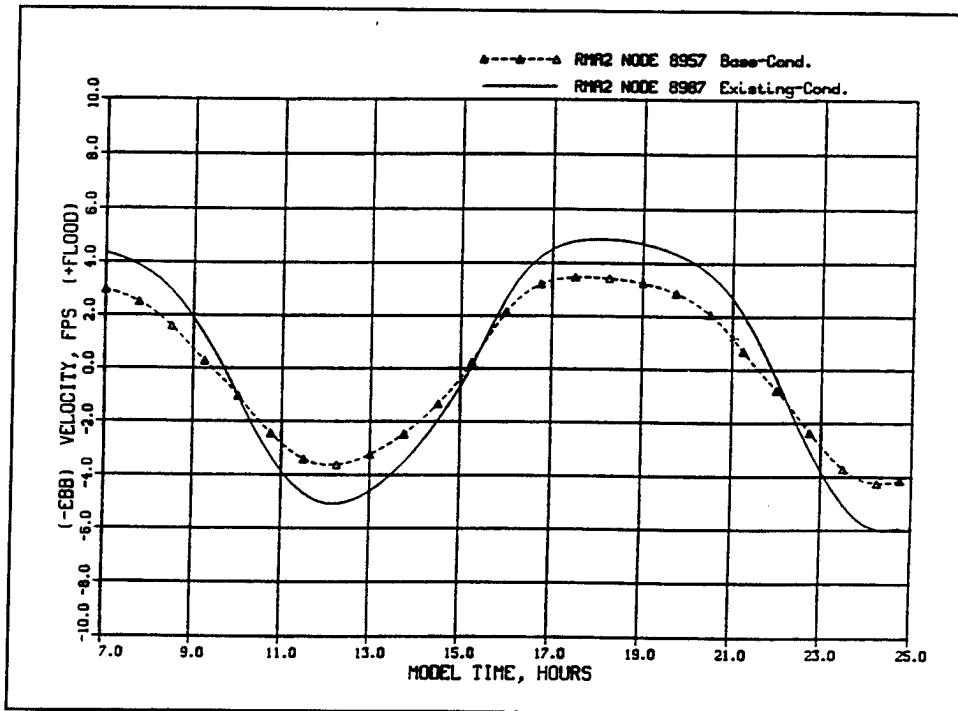
b. Velocity

Figure 19. Comparison of existing and base conditions of numerical results at river mile 17.52

Savannah Harbor, 17 January 1992

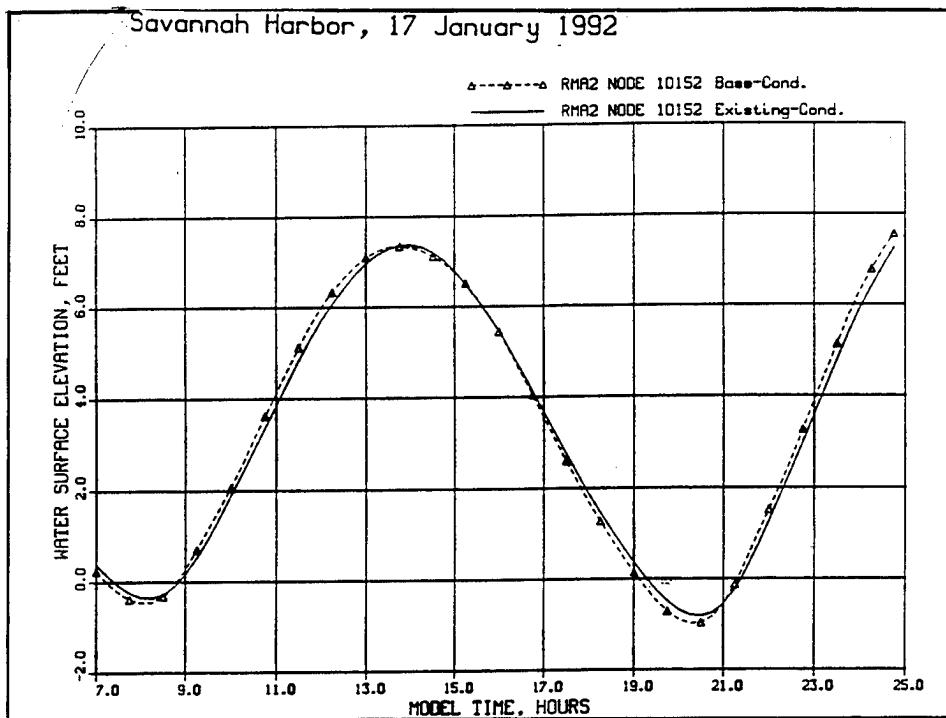


a. Water surface elevation

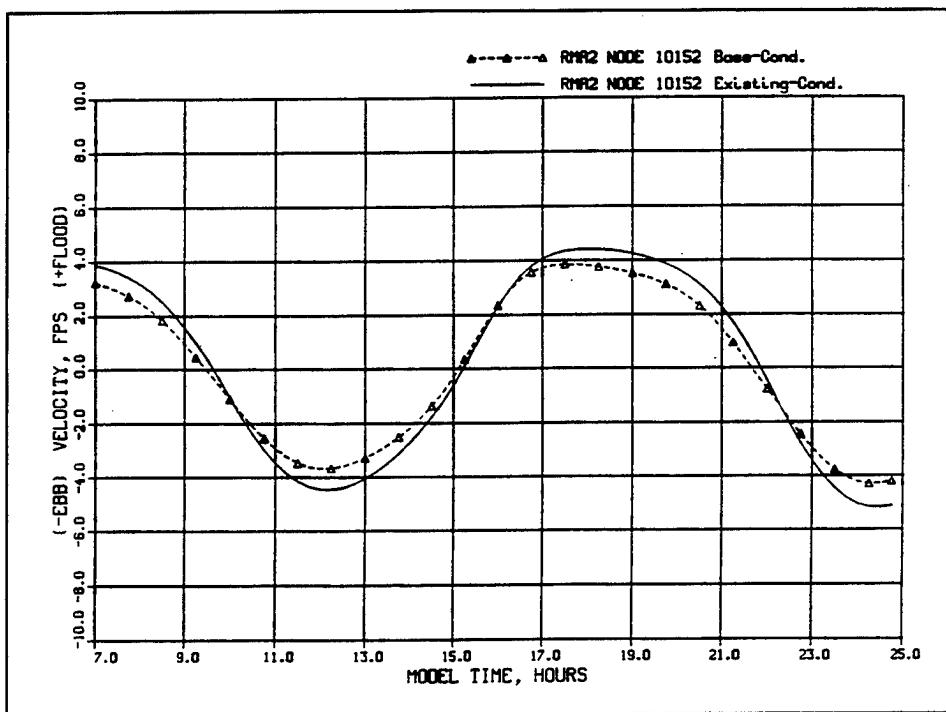


b. Velocity

Figure 20. Comparison of existing and base conditions of numerical results at river mile 15.05

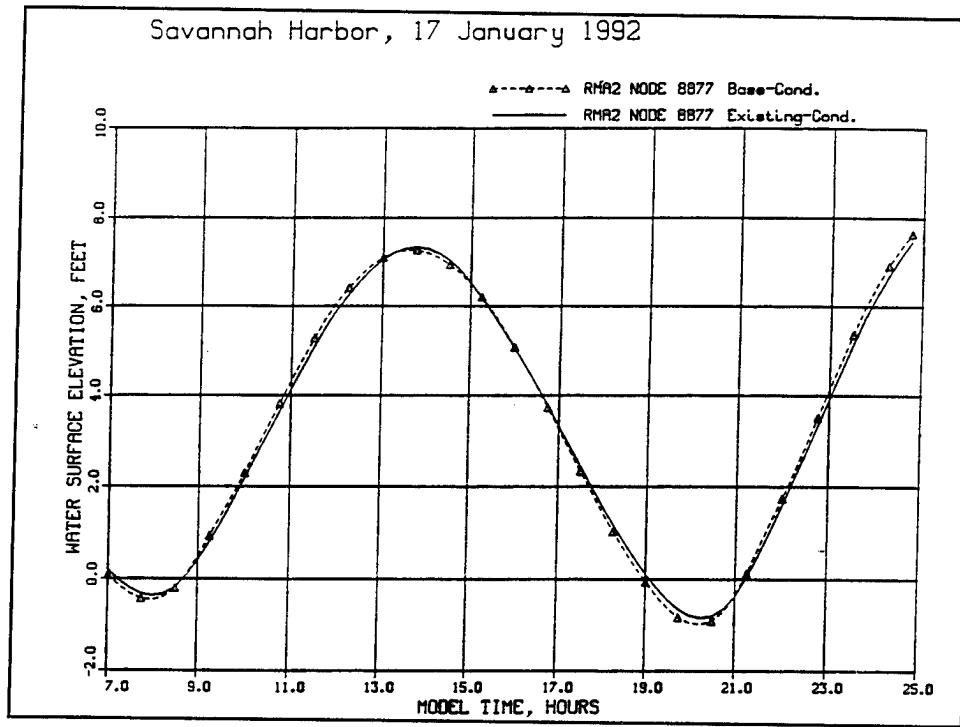


a. Water surface elevation

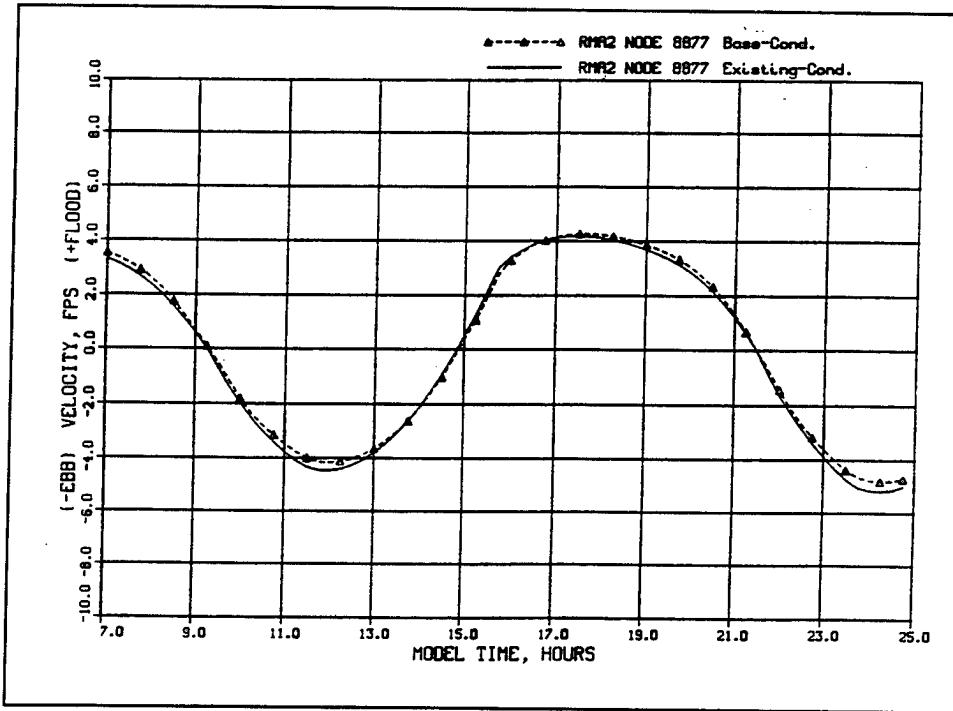


b. Velocity

Figure 21. Comparison of existing and base conditions of numerical results at river mile 13.77

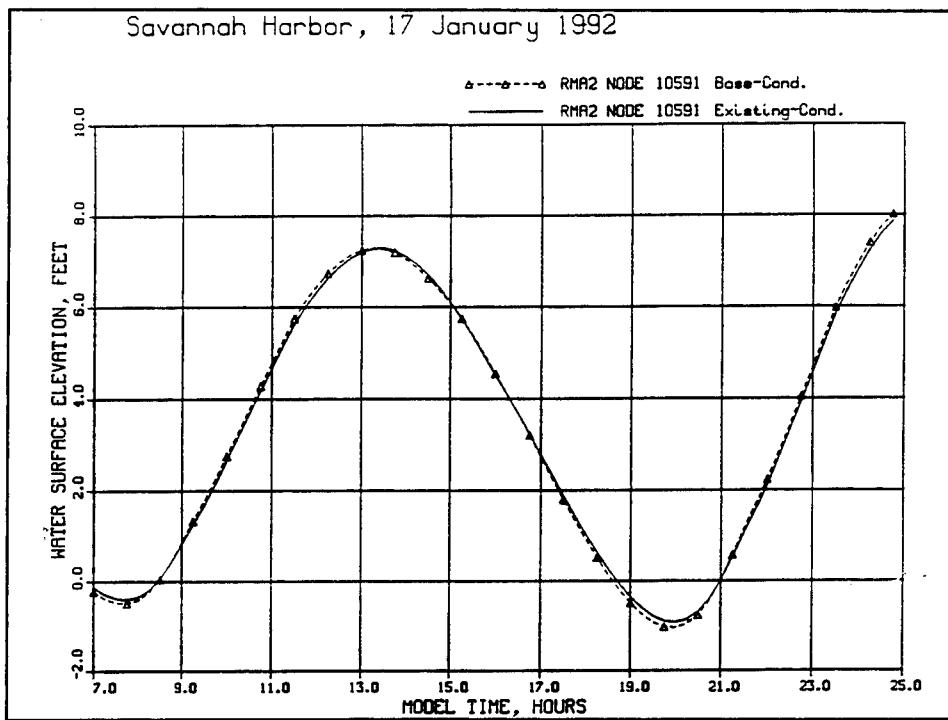


a. Water surface elevation

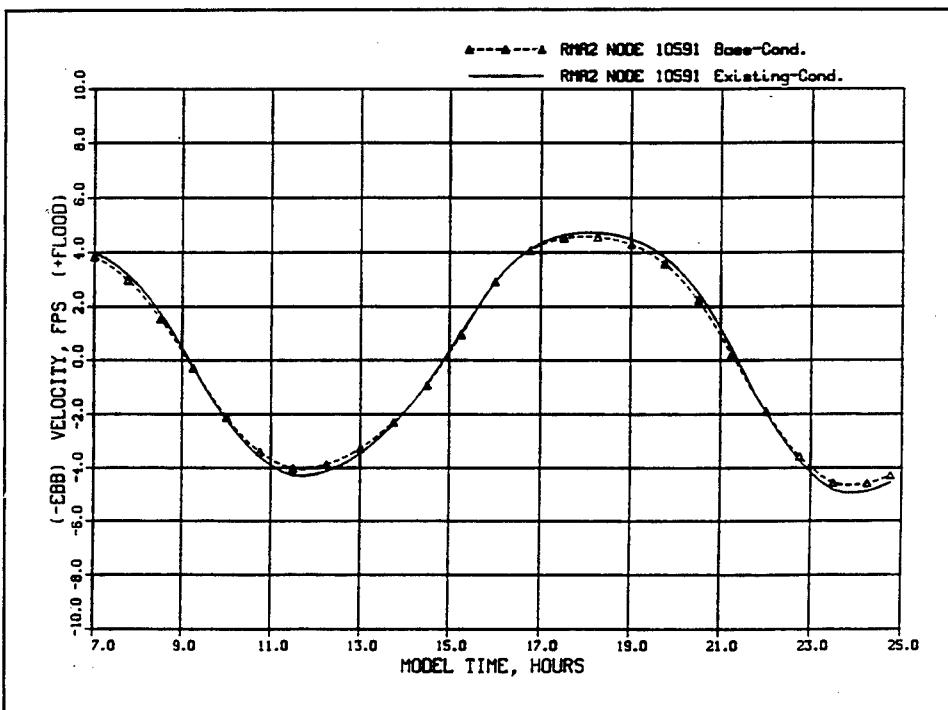


b. Velocity

Figure 22. Comparison of existing and base conditions of numerical results at river mile 11.09



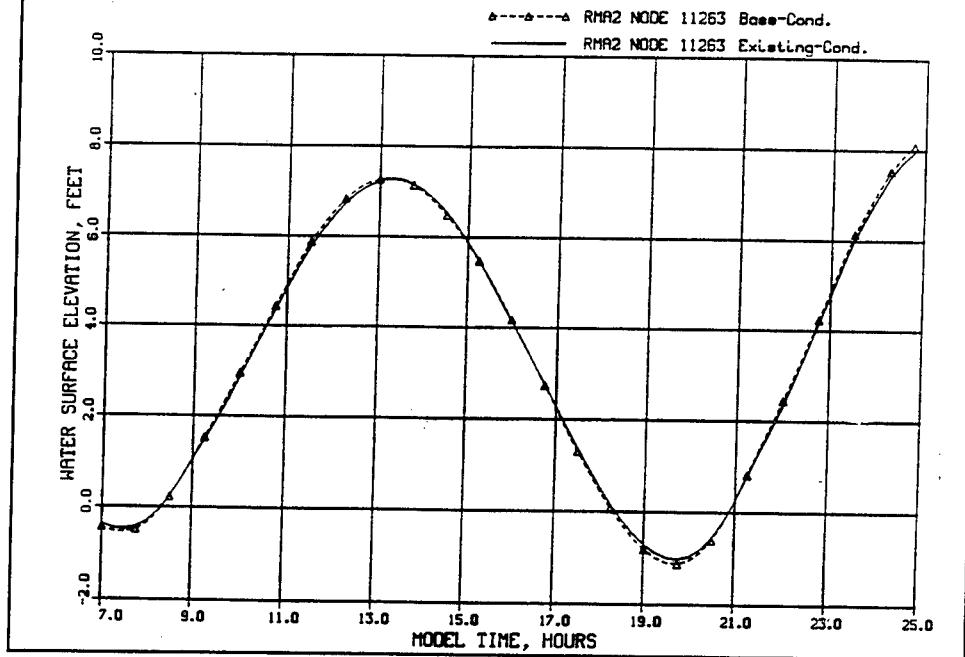
a. Water surface elevation



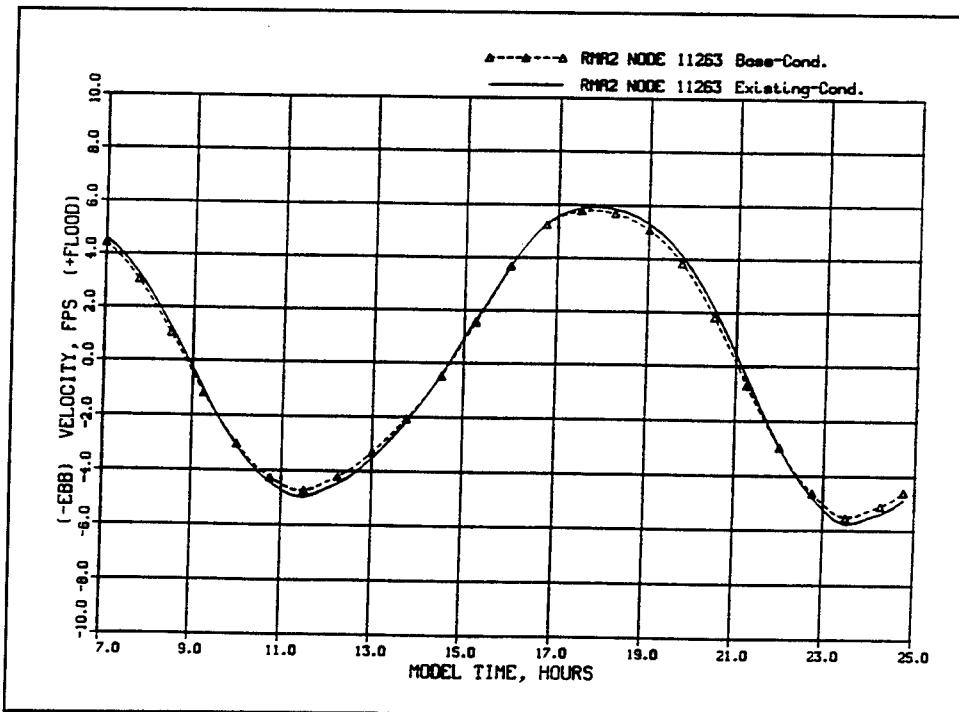
b. Velocity

Figure 23. Comparison of existing and base conditions of numerical results at river mile 7.39

Savannah Harbor, 17 January 1992

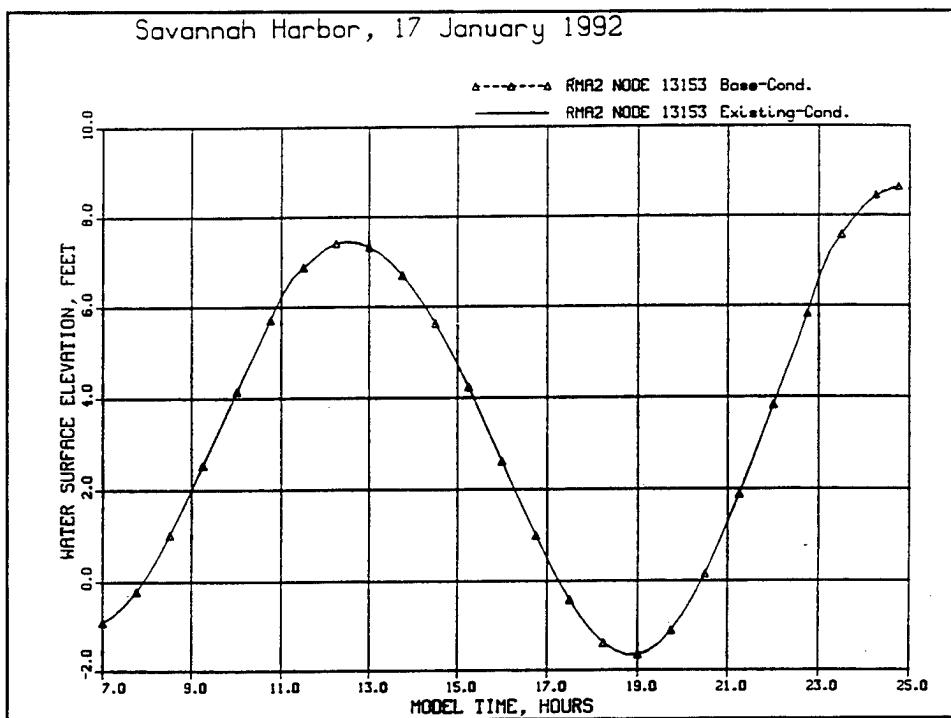


a. Water surface elevation

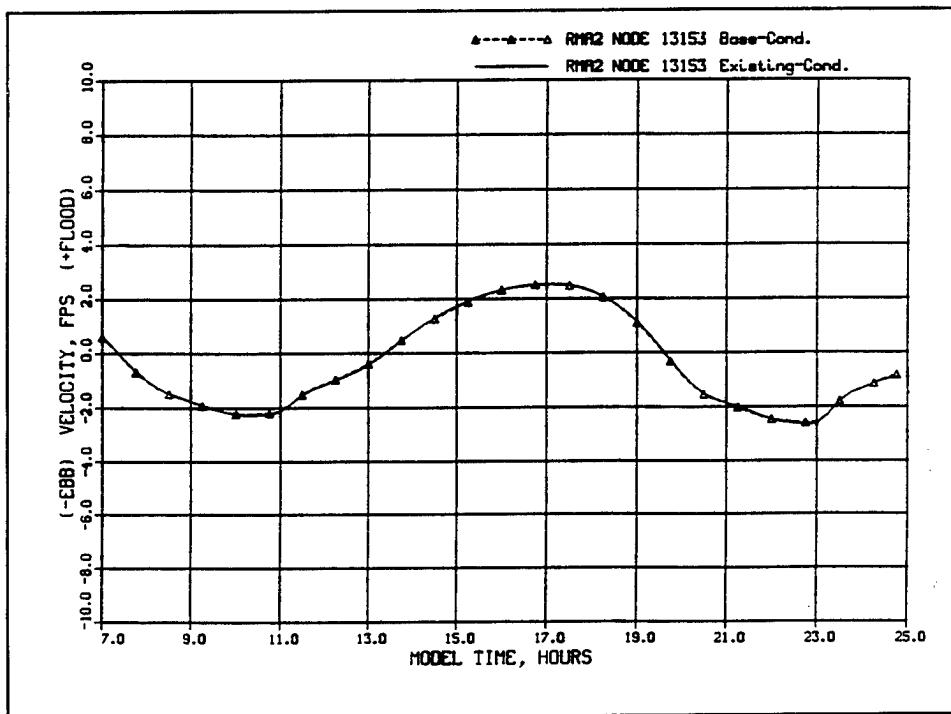


b. Velocity

Figure 24. Comparison of existing and base conditions of numerical results at river mile 5.50



a. Water surface elevation

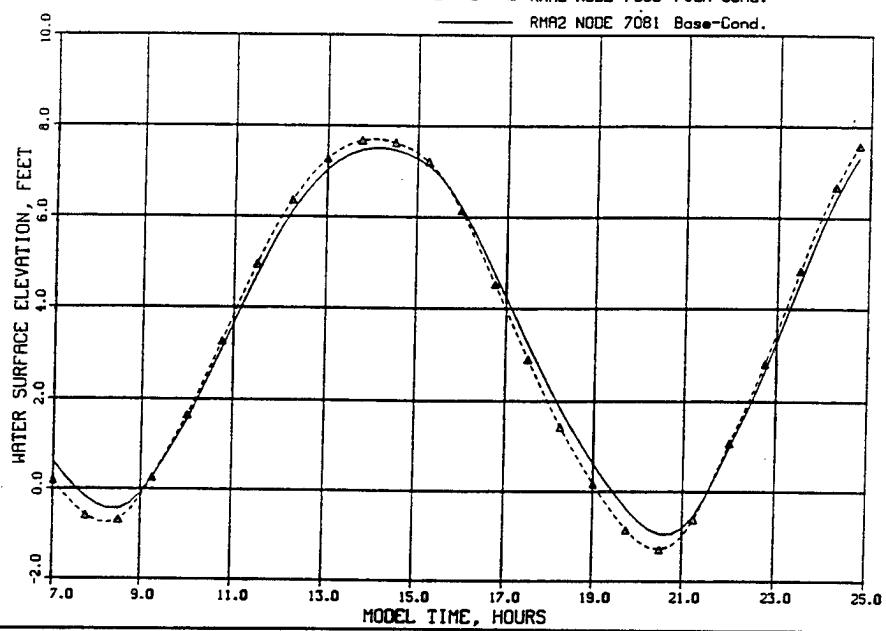


b. Velocity

Figure 25. Comparison of existing and base conditions of numerical results at river mile 0.29

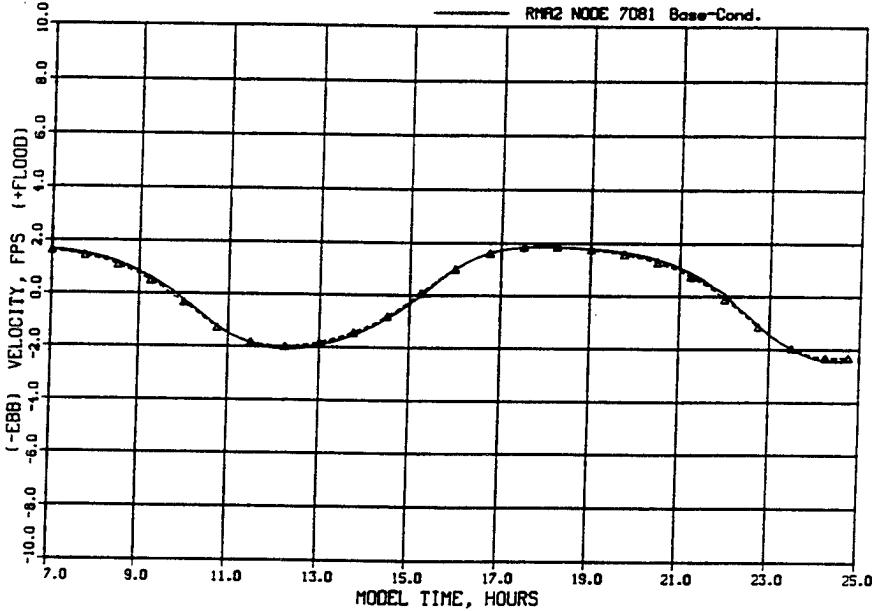
Savannah Harbor, 17 January 1992

△---△ RMA2 NODE 7088 Plan-Cond.
— RMA2 NODE 7081 Base-Cond.



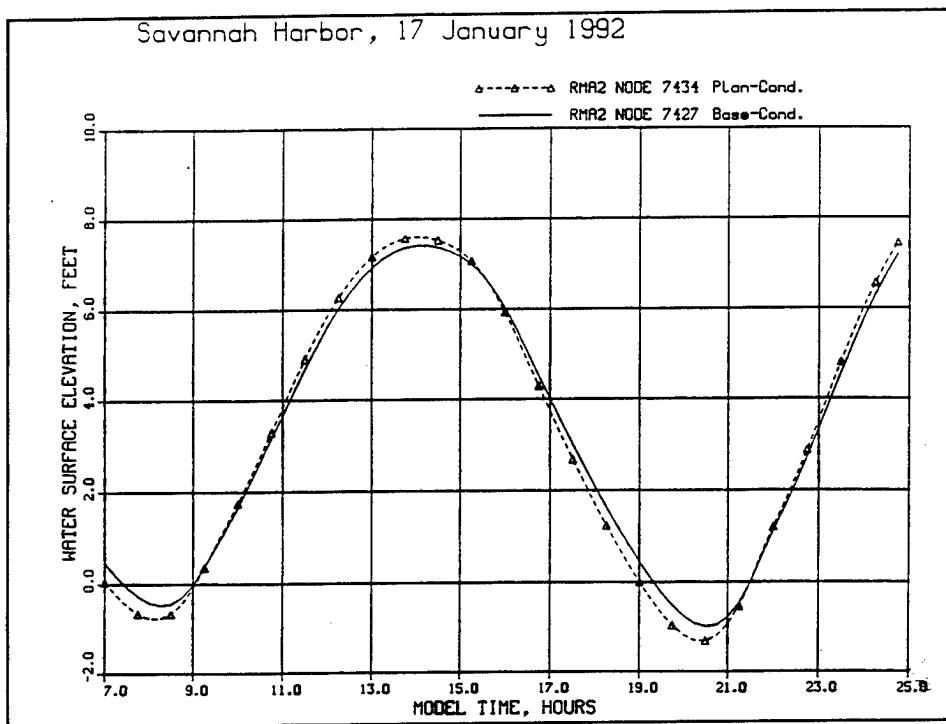
a. Water surface elevation

△---△ RMA2 NODE 7088 Plan-Cond.
— RMA2 NODE 7081 Base-Cond.

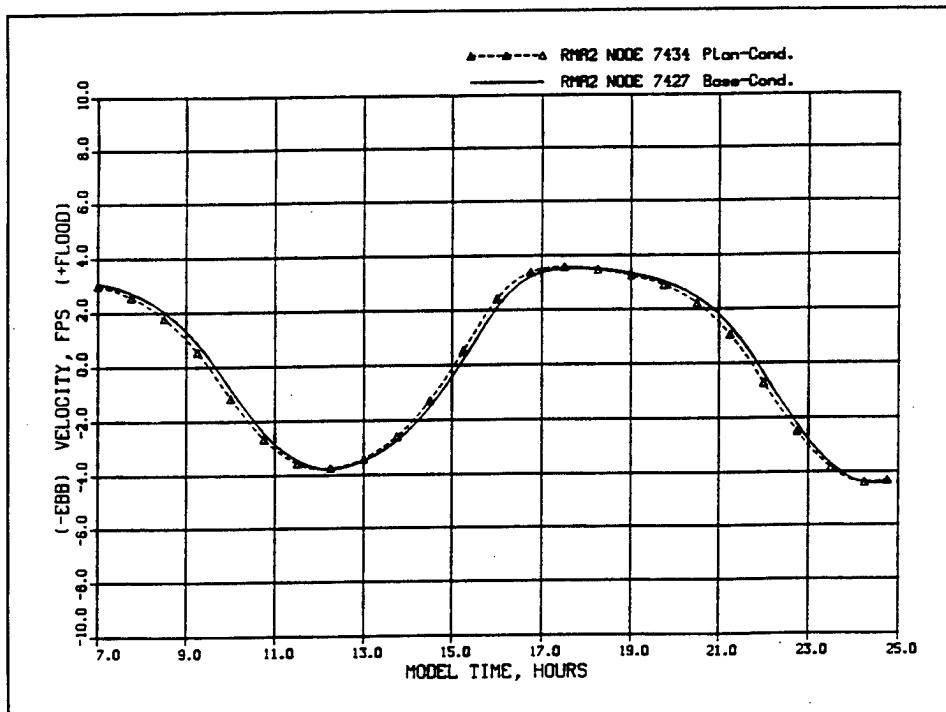


b. Velocity

Figure 26. Comparison of base and plan conditions of numerical results at river mile 18.75



a. Water surface elevation

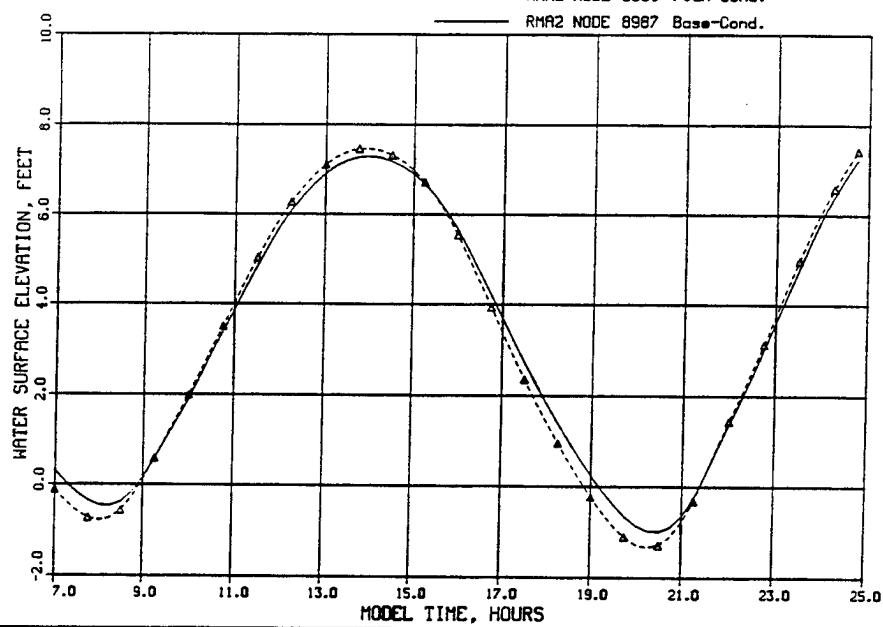


b. Velocity

Figure 27. Comparison of base and plan conditions of numerical results at river mile 17.52

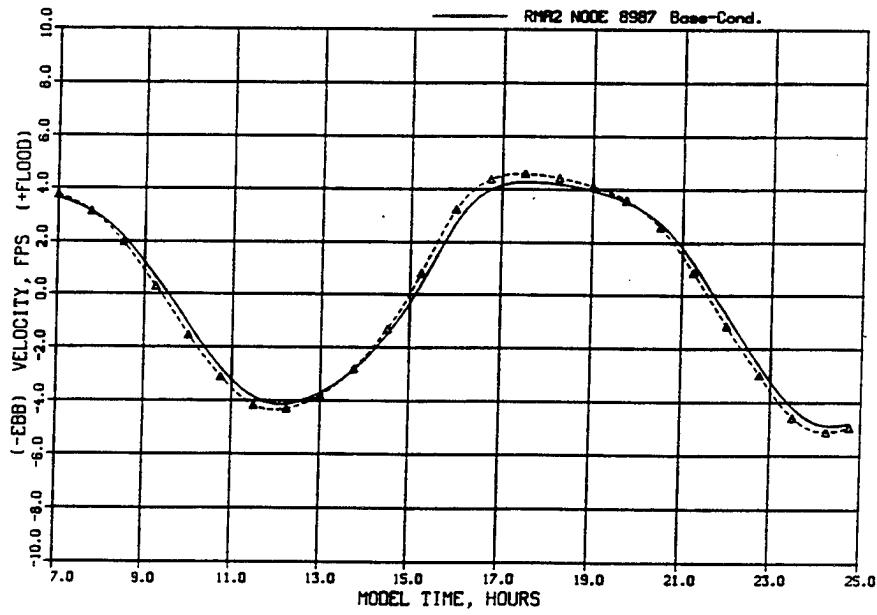
Savannah Harbor, 17 January 1992

----- RMA2 NODE 9001 Plan-Cond.
——— RMA2 NODE 8987 Base-Cond.



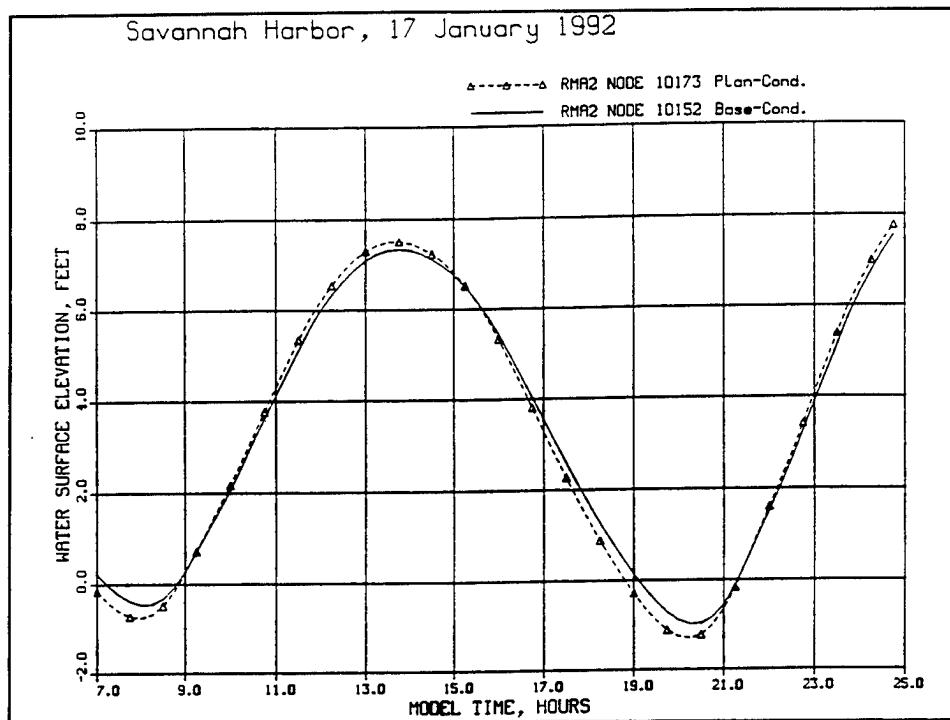
a. Water surface elevation

----- RMA2 NODE 9001 Plan-Cond.
——— RMA2 NODE 8987 Base-Cond.

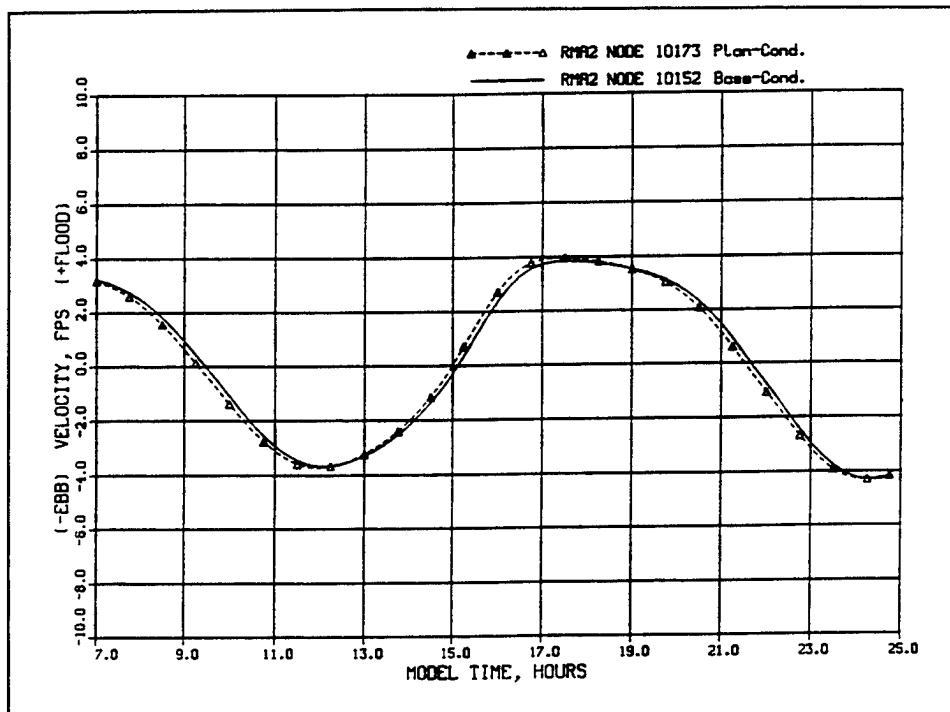


b. Velocity

Figure 28. Comparison of base and plan conditions of numerical results at river mile 15.05



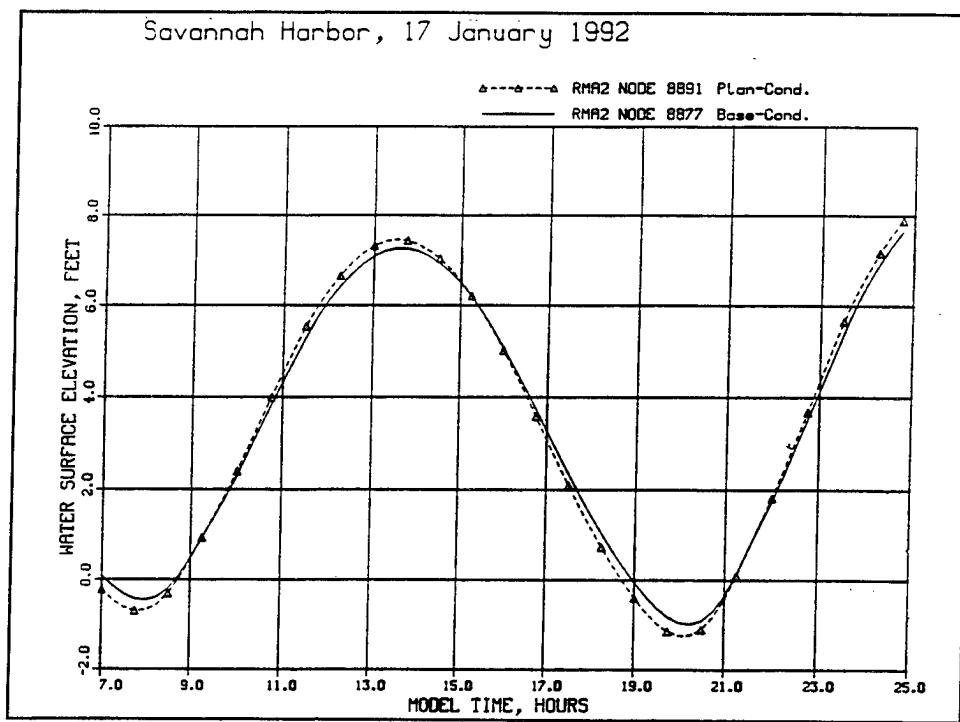
a. Water surface elevation



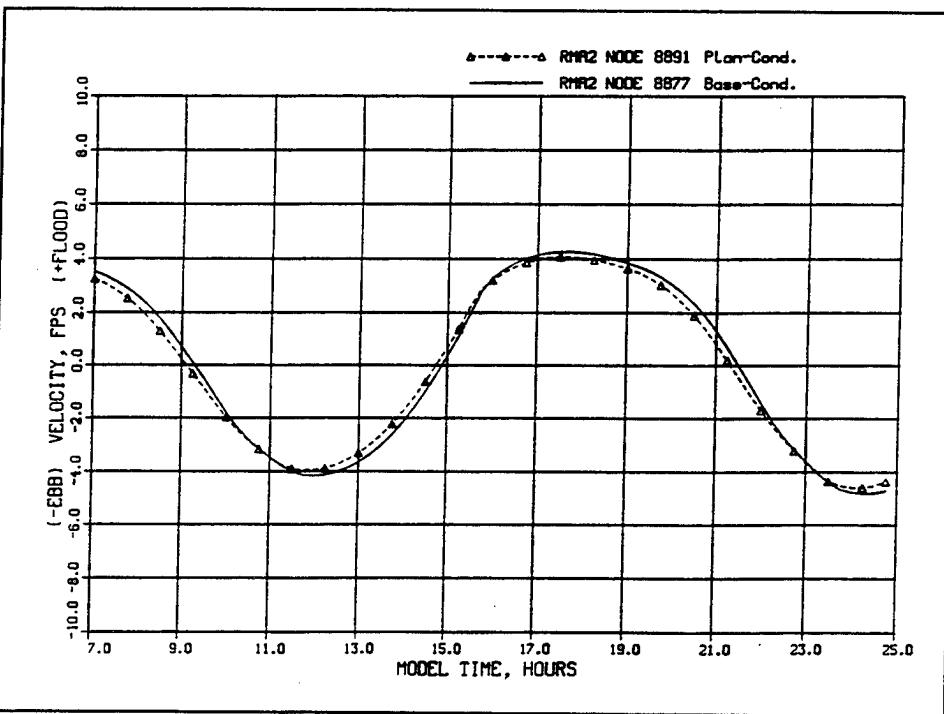
b. Velocity

Figure 29. Comparison of base and plan conditions of numerical results at river mile 13.77

Savannah Harbor, 17 January 1992

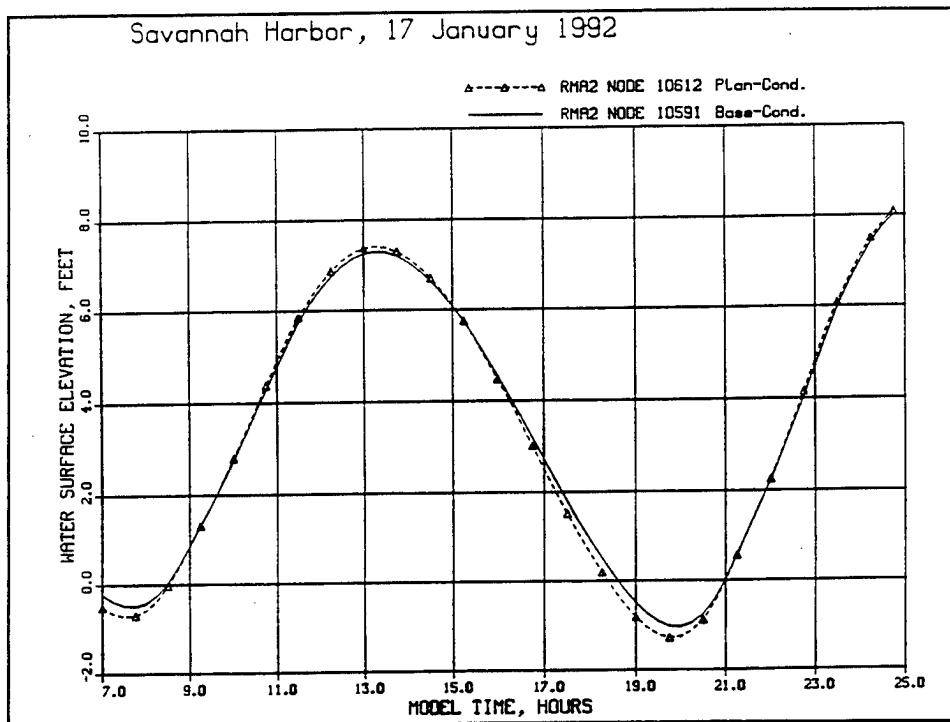


a. Water surface elevation

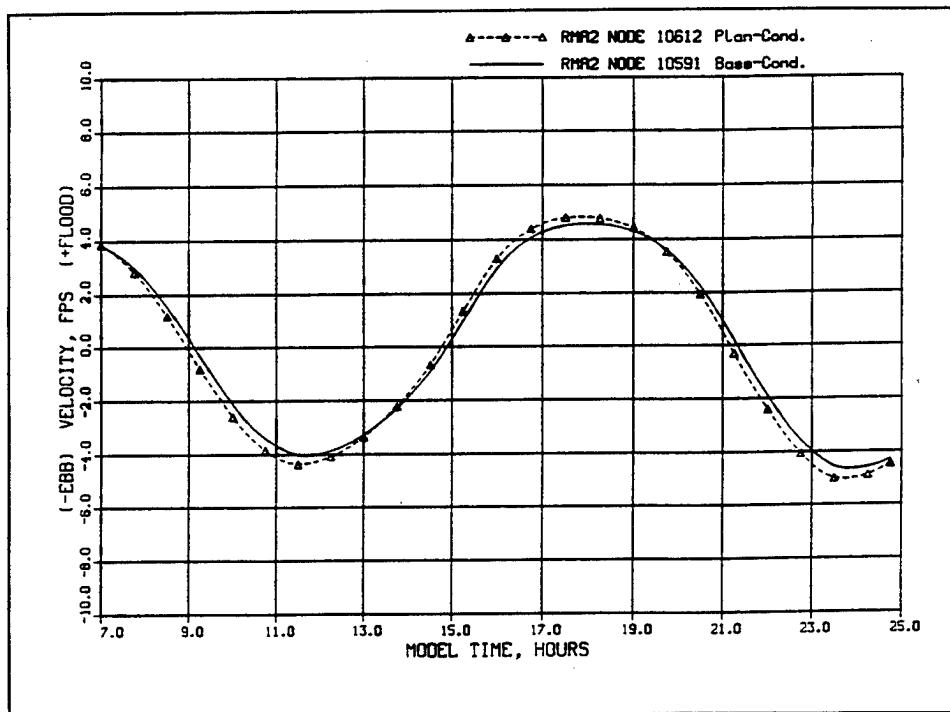


b. Velocity

Figure 30. Comparison of base and plan conditions of numerical results at river mile 11.09



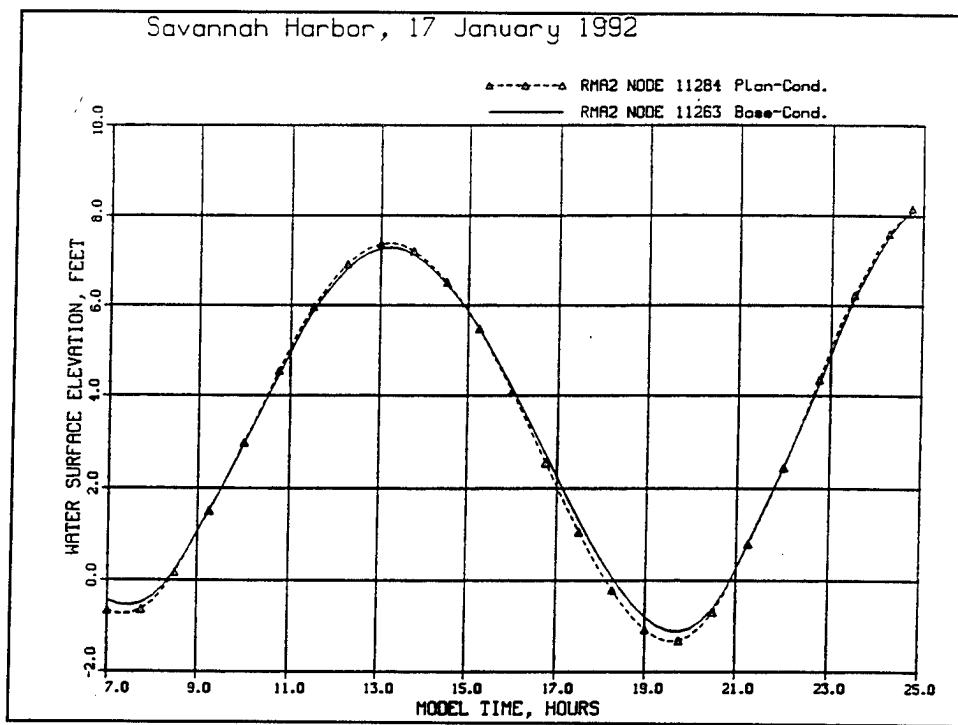
a. Water surface elevation



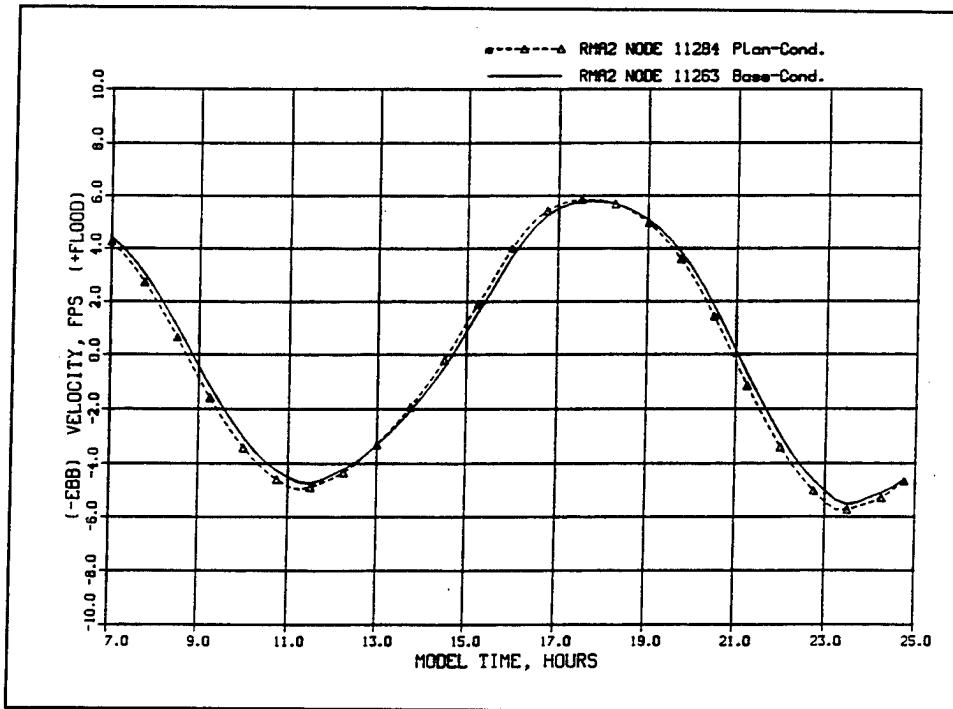
b. Velocity

Figure 31. Comparison of base and plan conditions of numerical results at river mile 7.39

Savannah Harbor, 17 January 1992

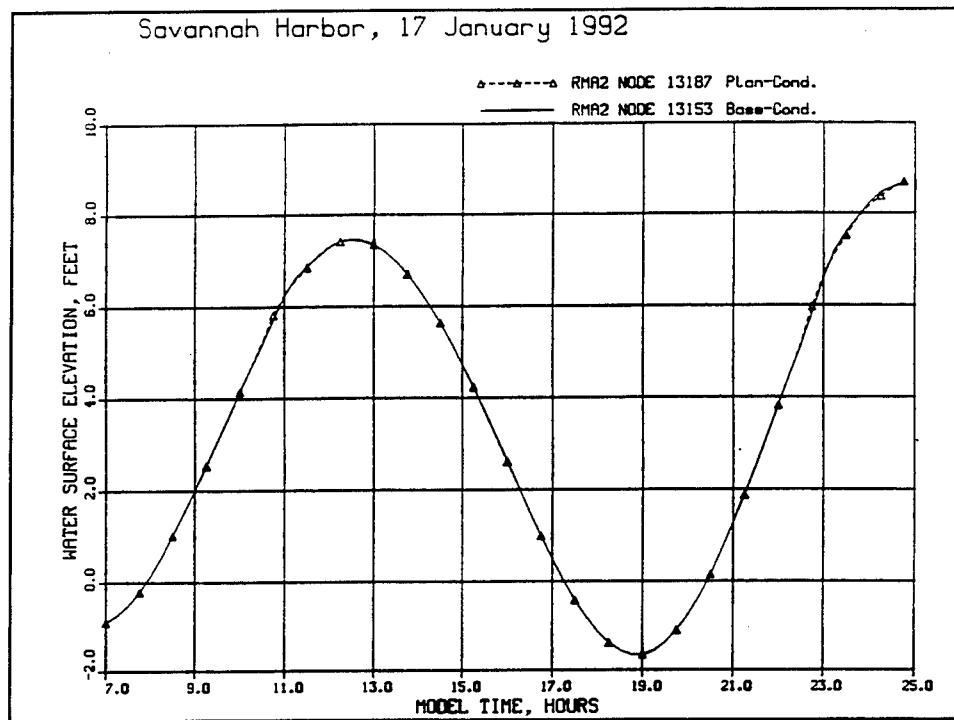


a. Water surface elevation

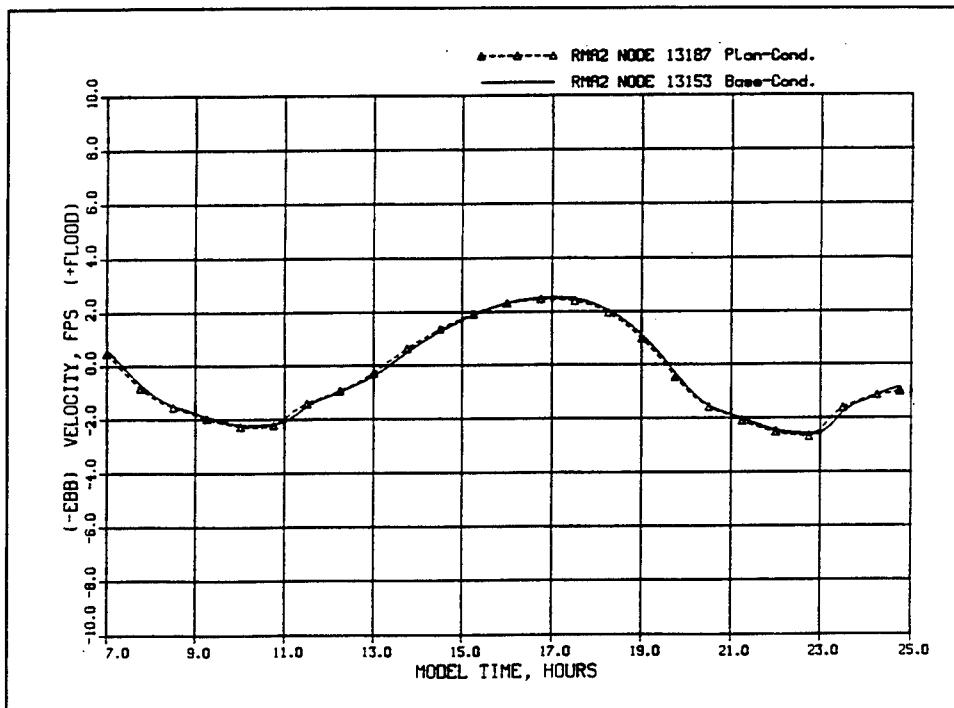


b. Velocity

Figure 32. Comparison of base and plan conditions of numerical results at river mile 5.50

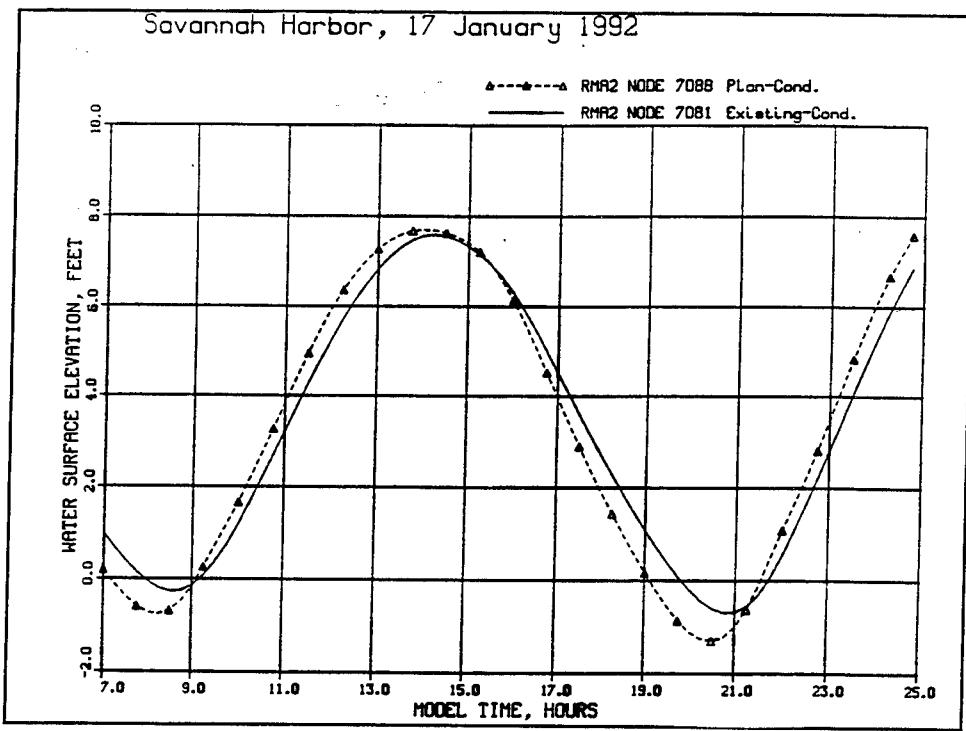


a. Water surface elevation

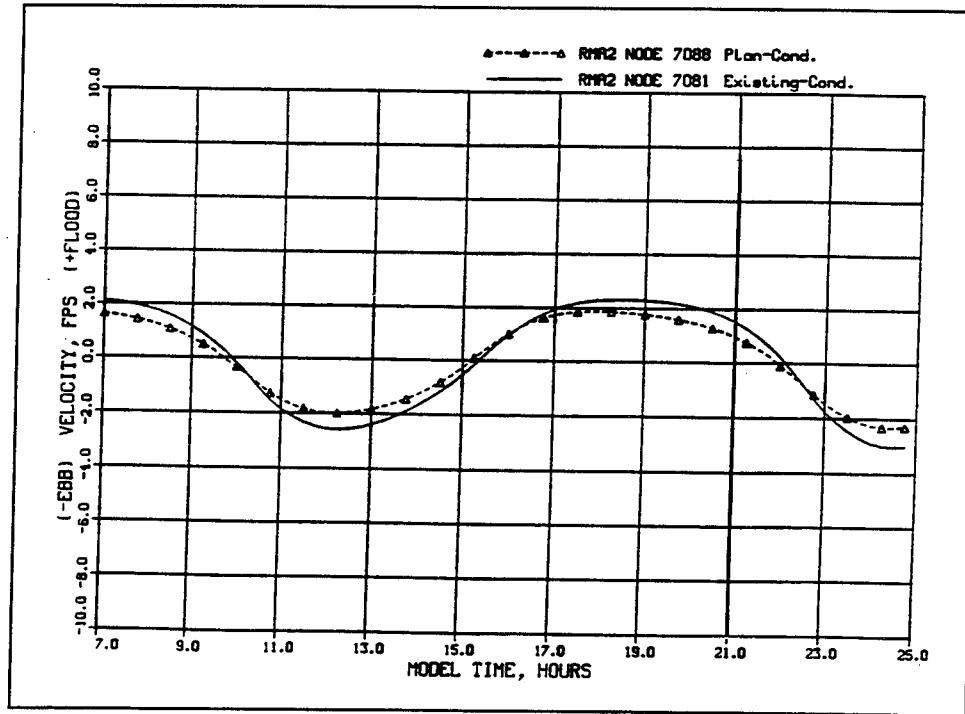


b. Velocity

Figure 33. Comparison of base and plan conditions of numerical results at river mile 0.29

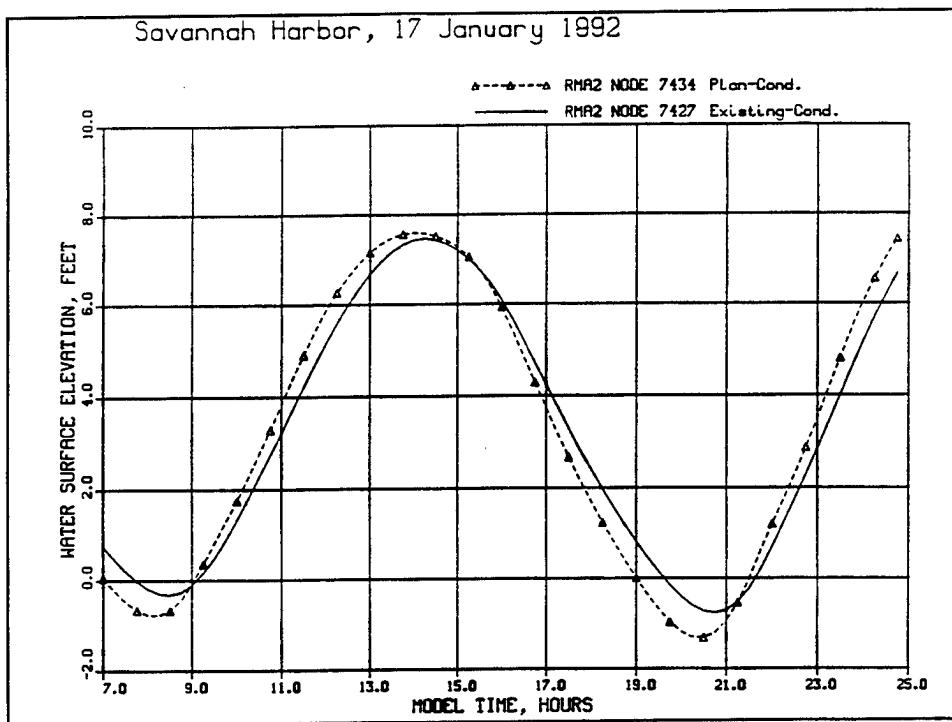


a. Water surface elevation

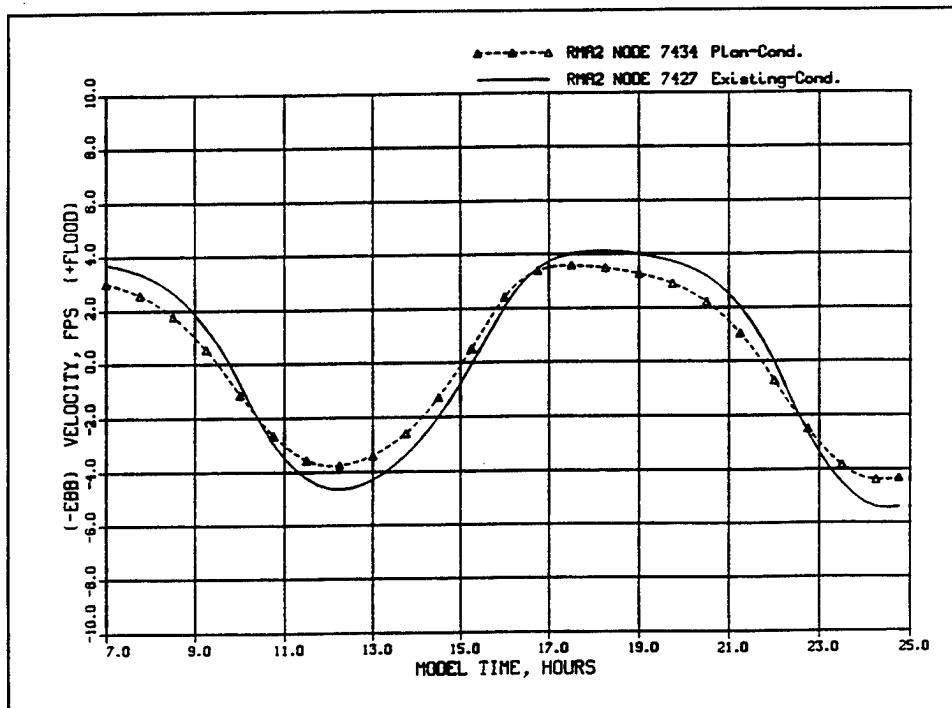


b. Velocity

Figure 34. Comparison of existing and plan conditions of numerical results at river mile 18.75



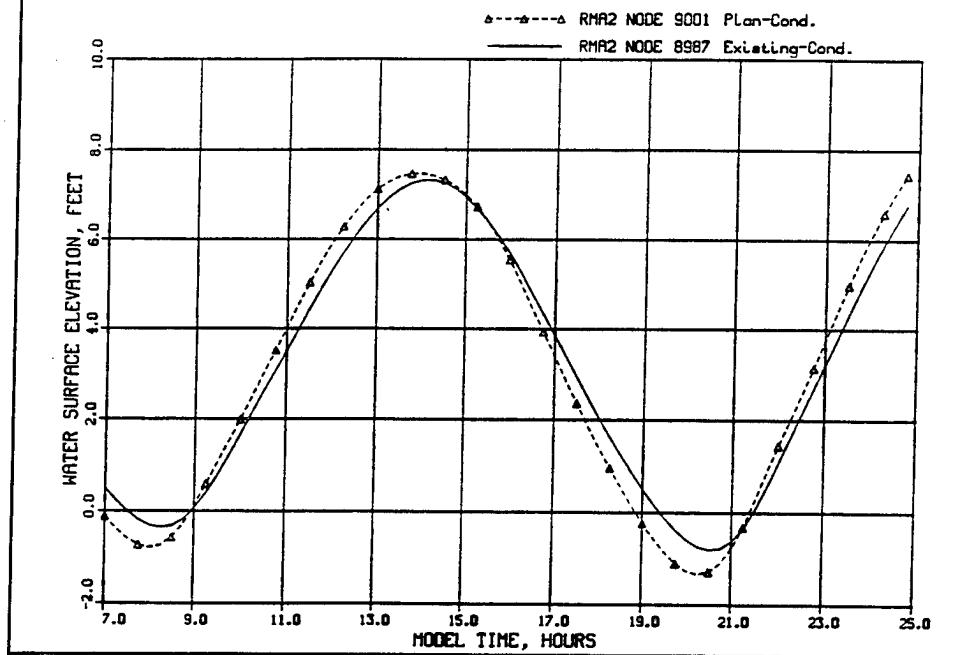
a. Water surface elevation



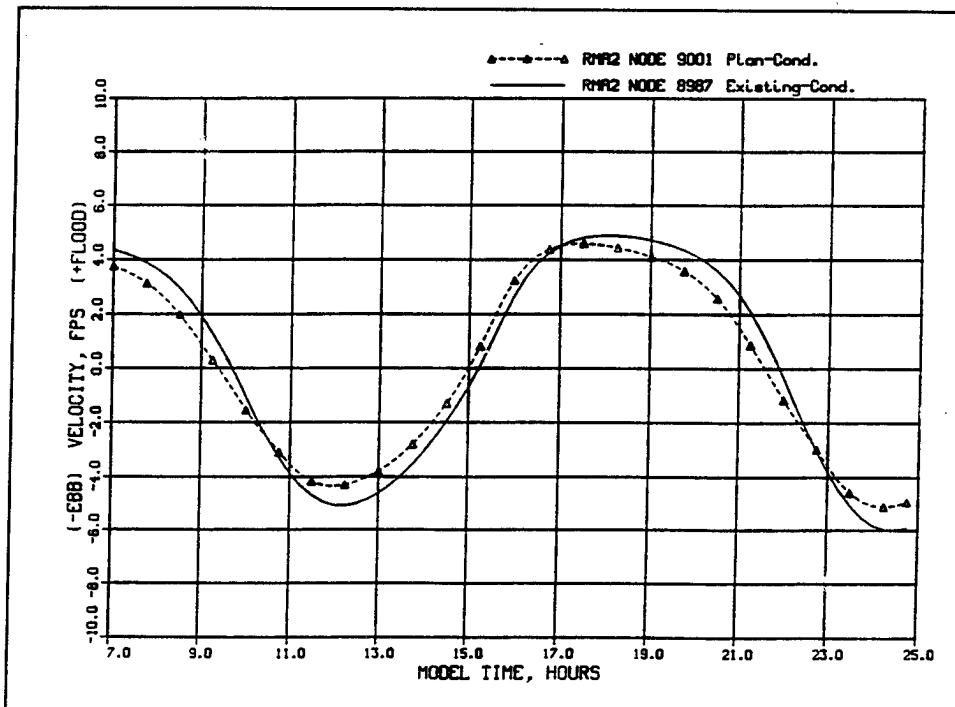
b. Velocity

Figure 35. Comparison of existing and plan conditions of numerical results at river mile 17.52

Savannah Harbor, 17 January 1992

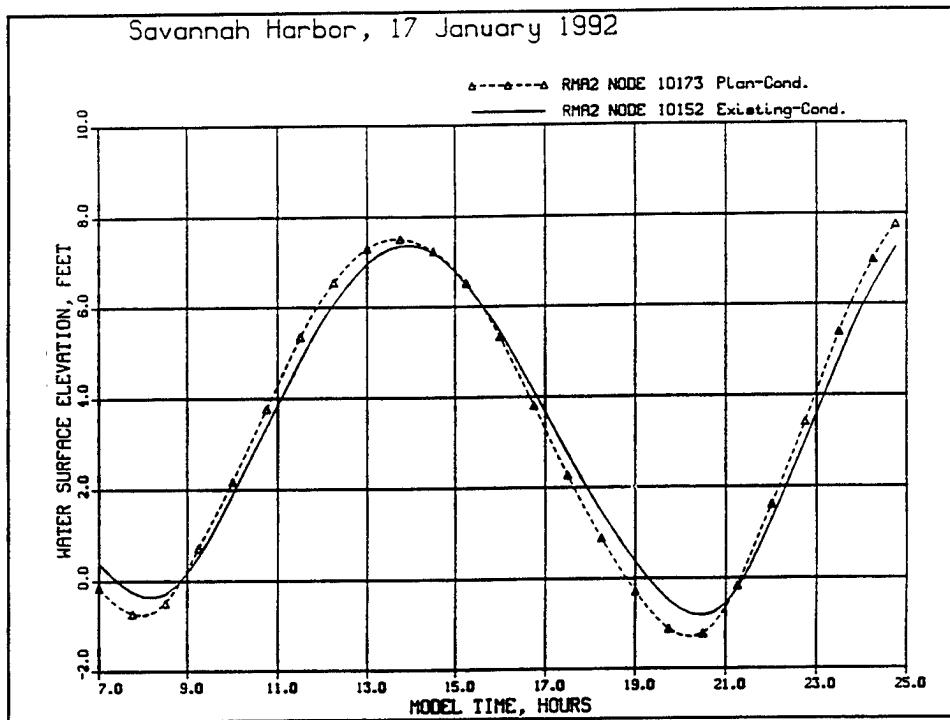


a. Water surface elevation

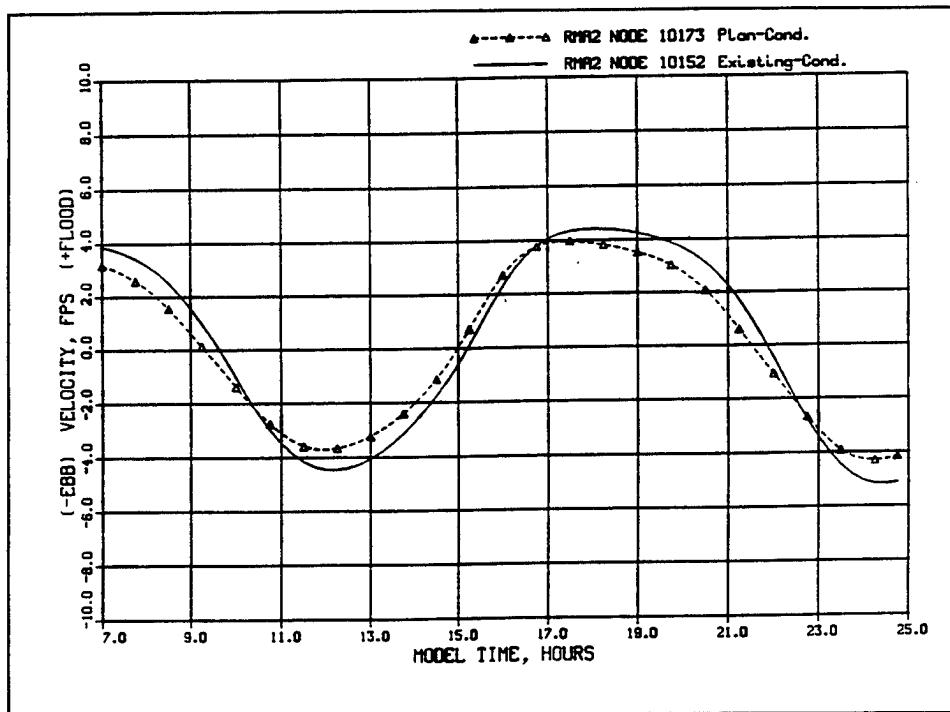


b. Velocity

Figure 36. Comparison of existing and plan conditions of numerical results at river mile 15.05



a. Water surface elevation

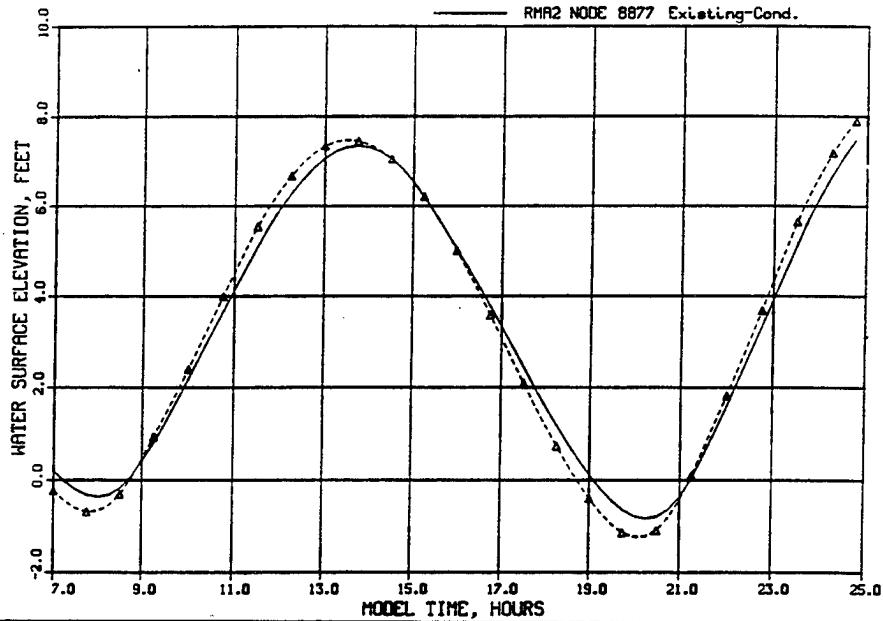


b. Velocity

Figure 37. Comparison of existing and plan conditions of numerical results at river mile 13.77

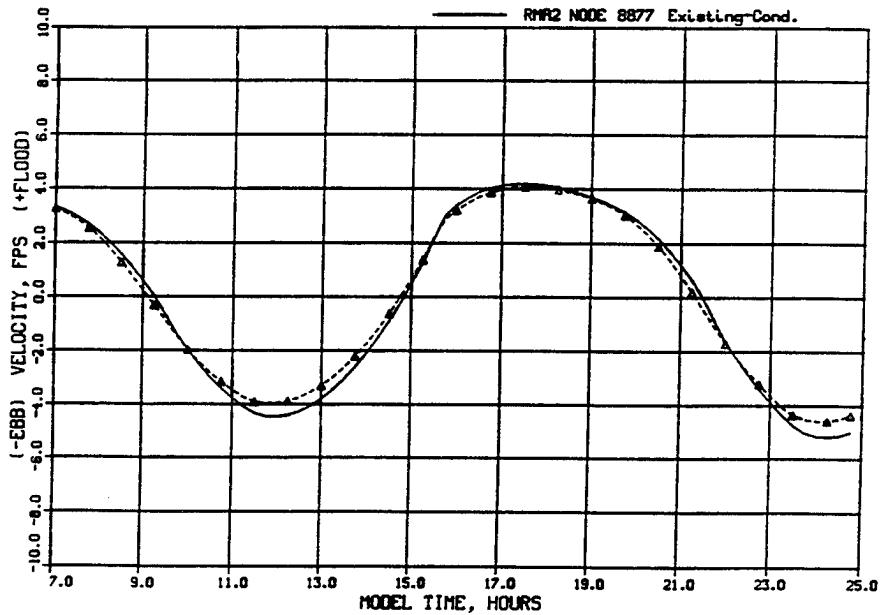
Savannah Harbor, 17 January 1992

----- RMR2 NODE 8891 Plan-Cond.
——— RMR2 NODE 8877 Existing-Cond.



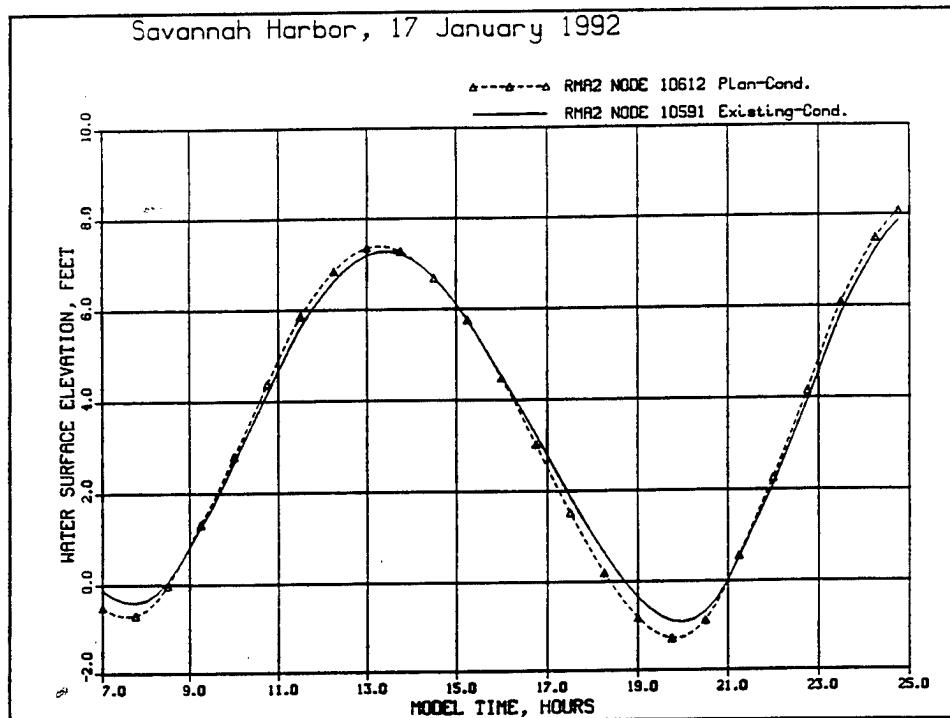
a. Water surface elevation

----- RMR2 NODE 8891 Plan-Cond.
——— RMR2 NODE 8877 Existing-Cond.

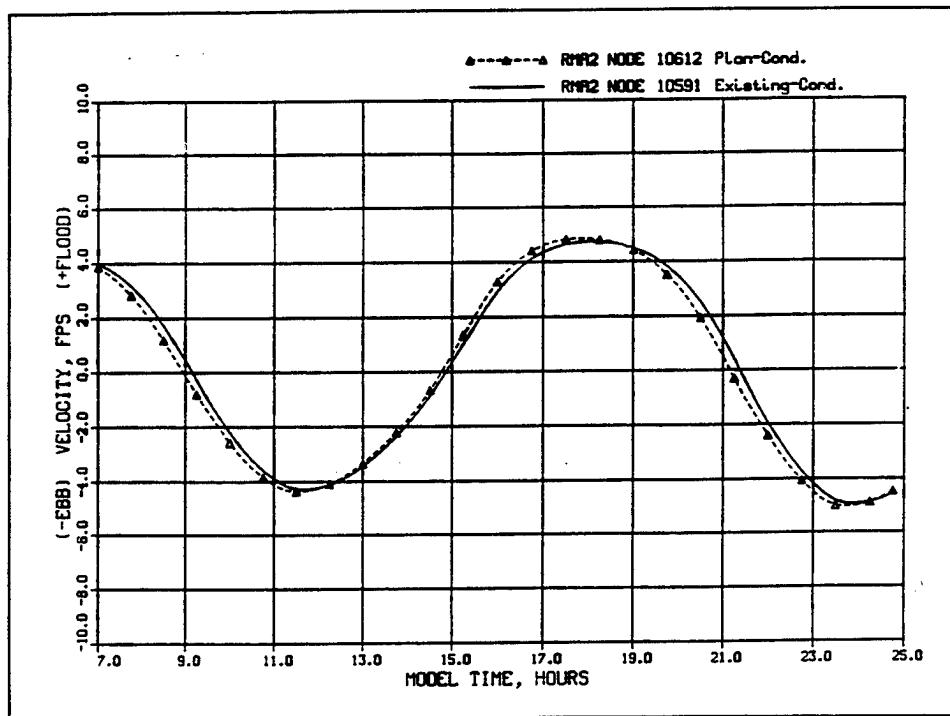


b. Velocity

Figure 38. Comparison of existing and plan conditions of numerical results at river mile 11.09

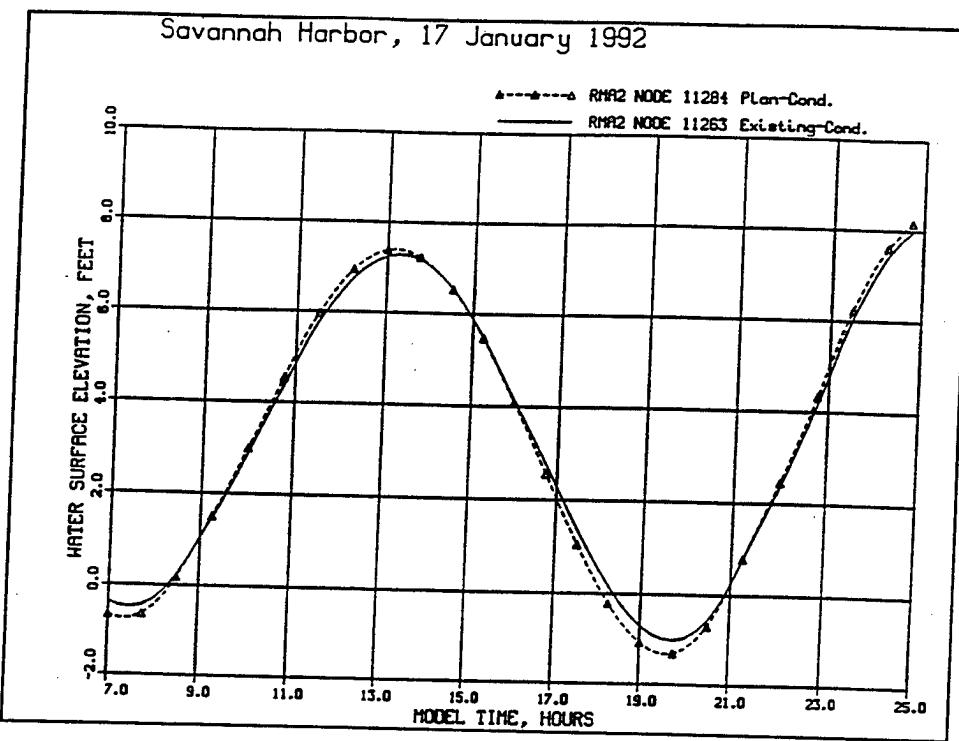


a. Water surface elevation

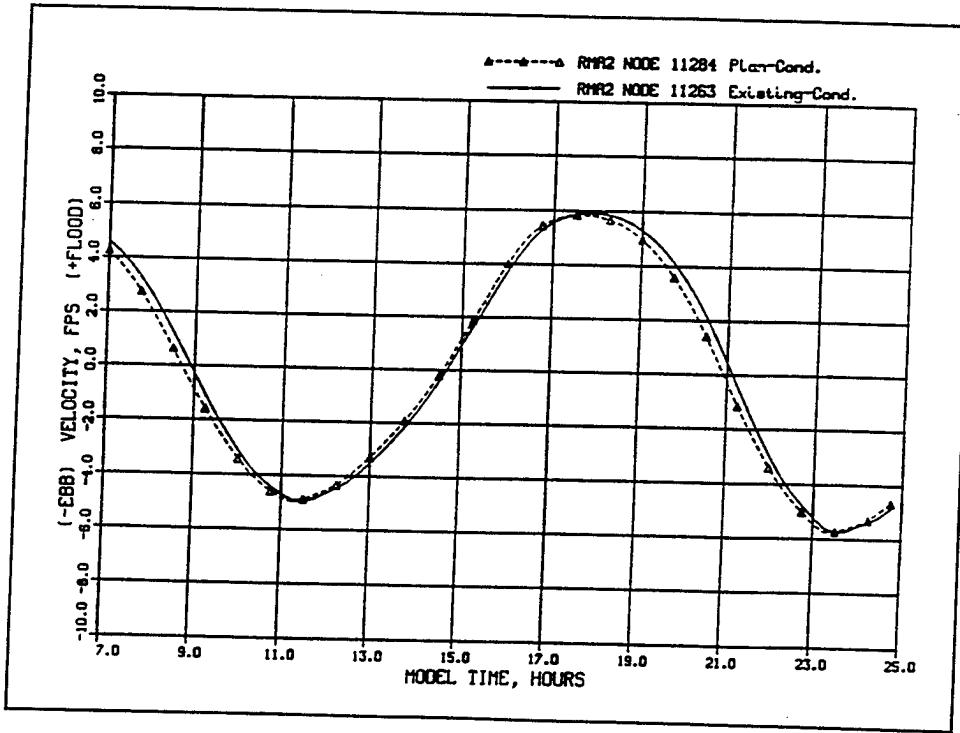


b. Velocity

Figure 39. Comparison of existing and plan conditions of numerical results at river mile 7.39

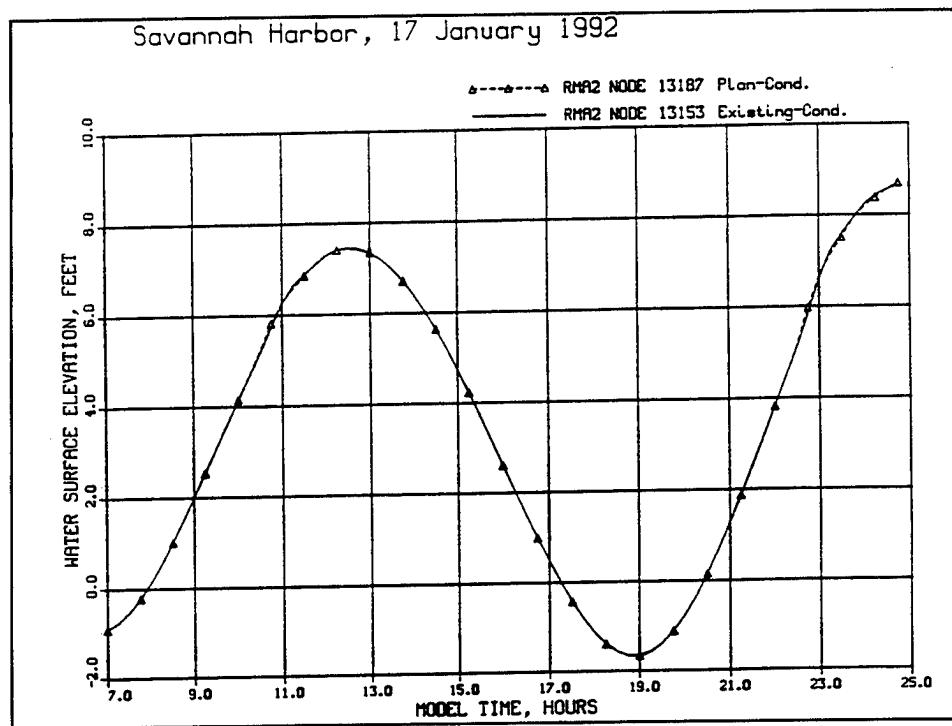


a. Water surface elevation

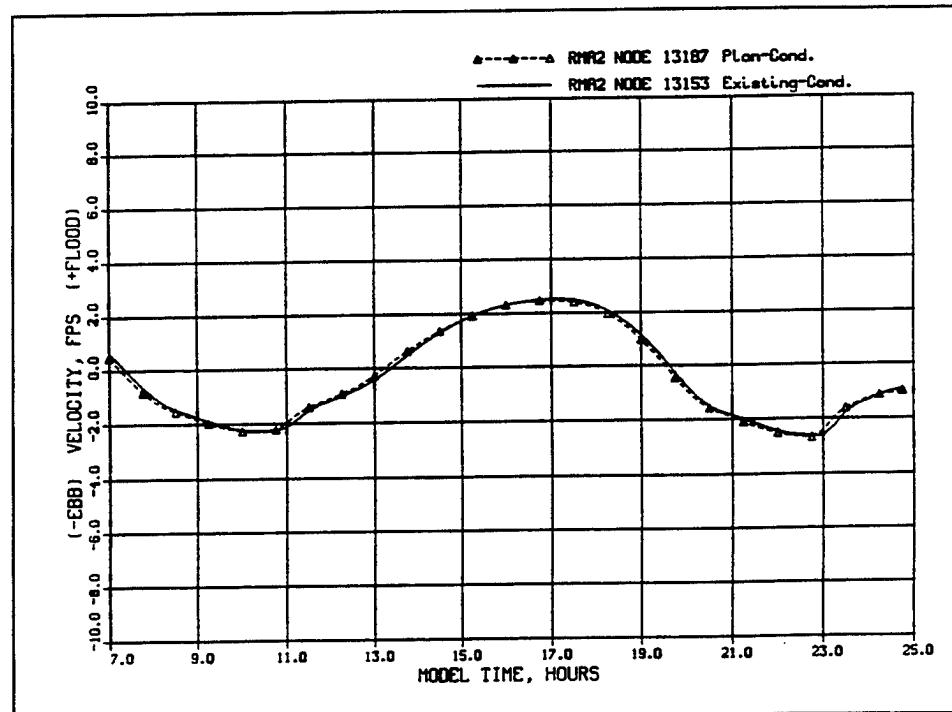


b. Velocity

Figure 40. Comparison of existing and plan conditions of numerical results at river mile 5.50



a. Water surface elevation



b. Velocity

Figure 41. Comparison of existing and plan conditions of numerical results at river mile 0.29

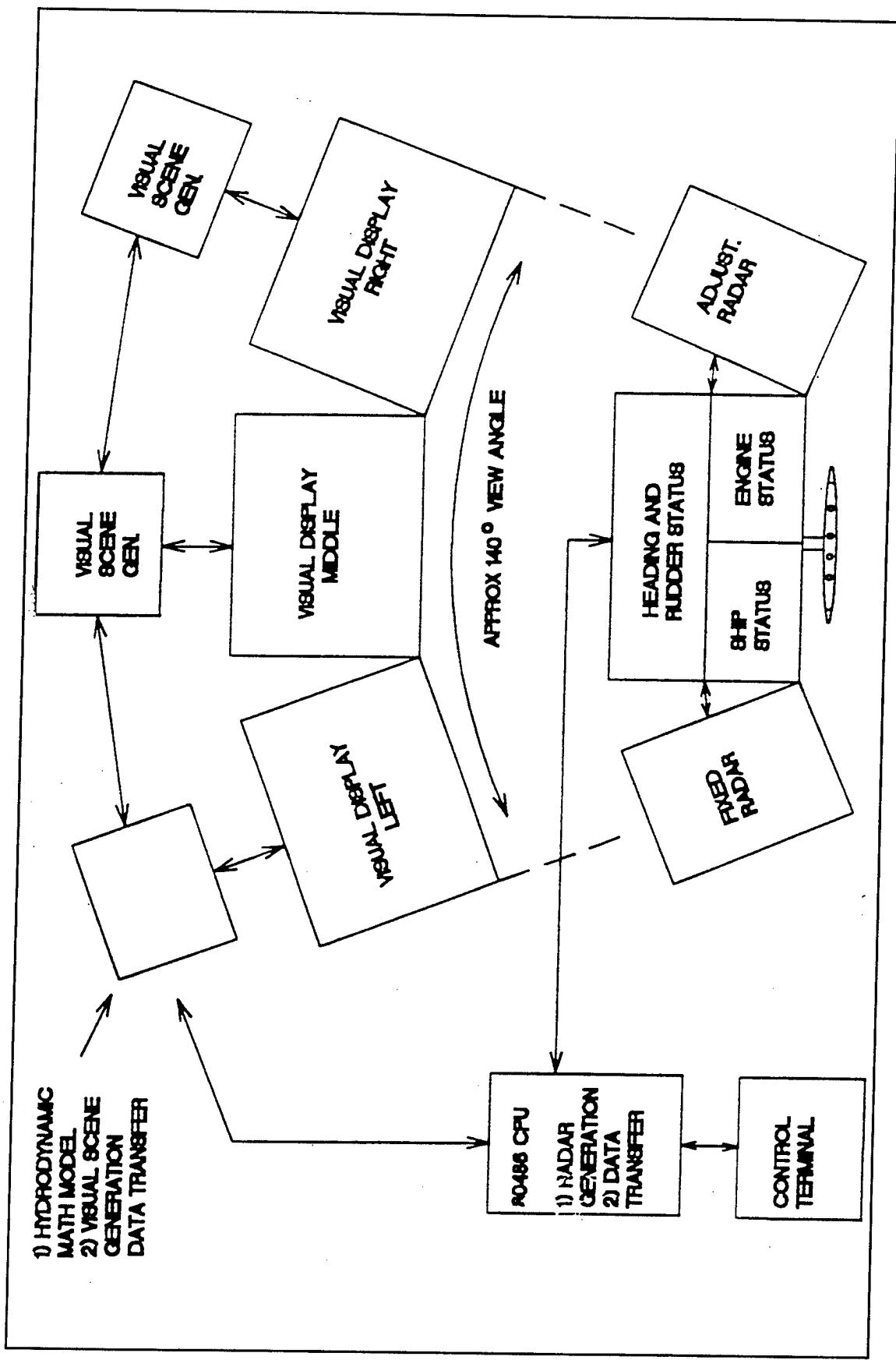


Figure 42. Simulation setup

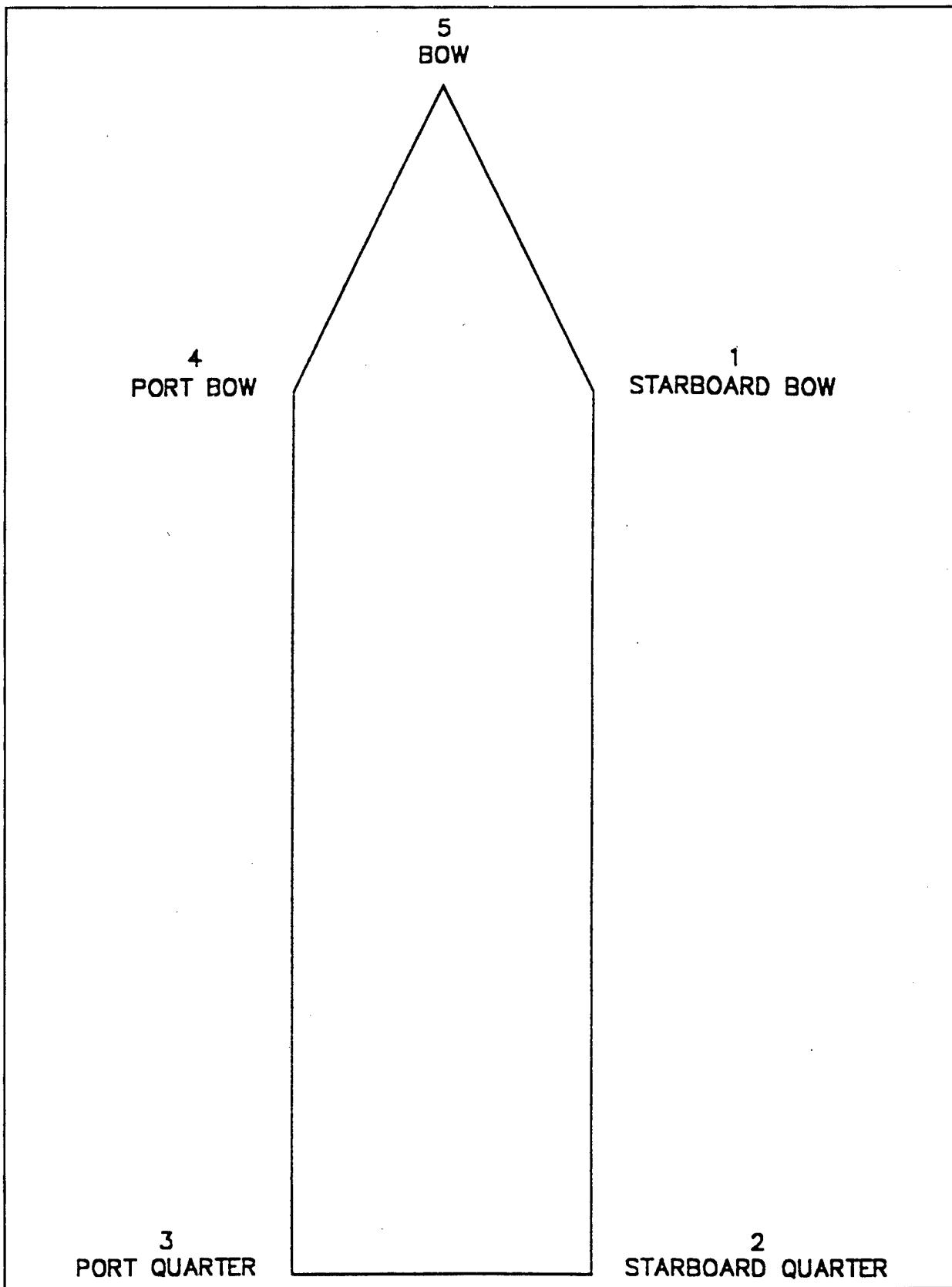
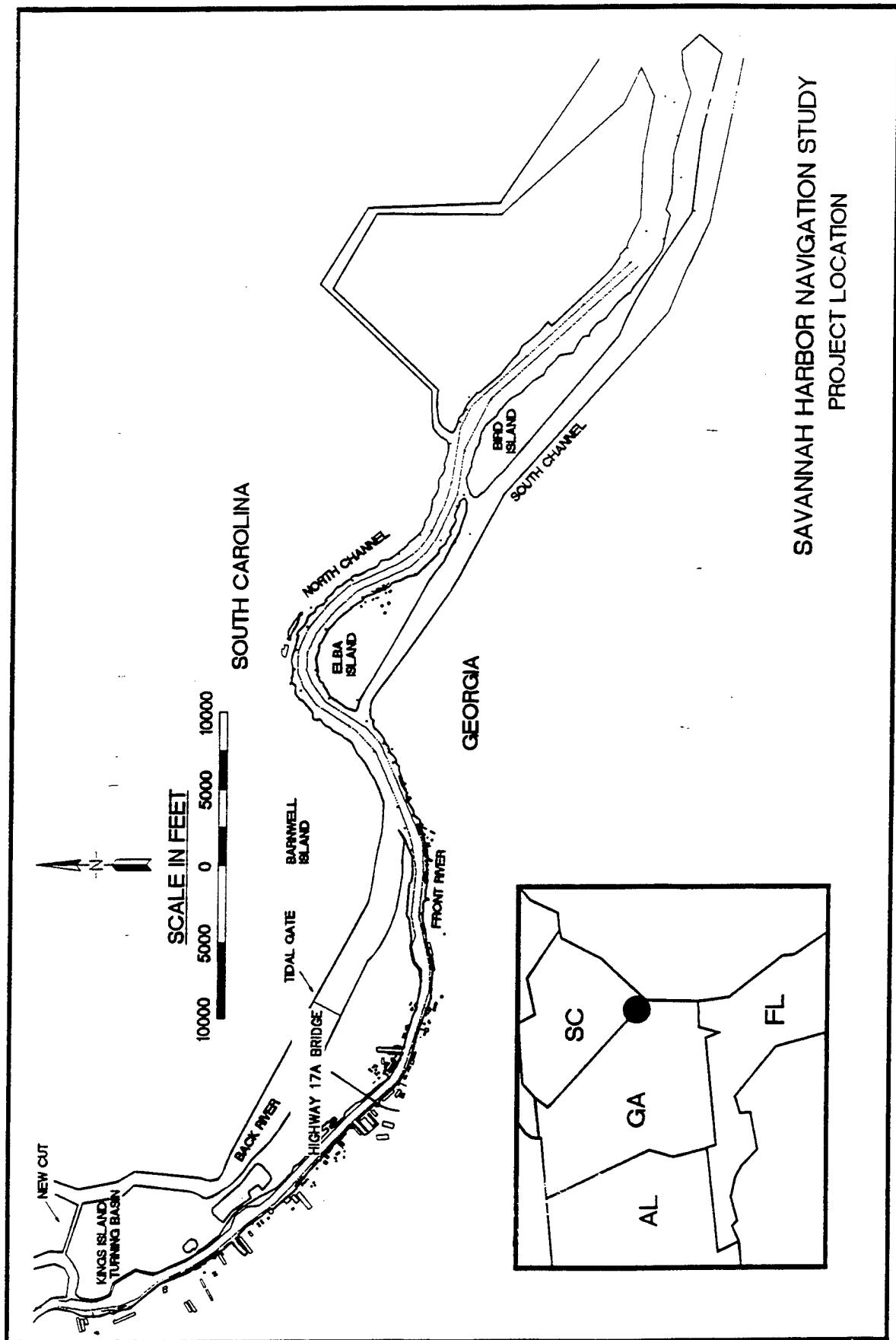


Figure 43. Tug availability and placement



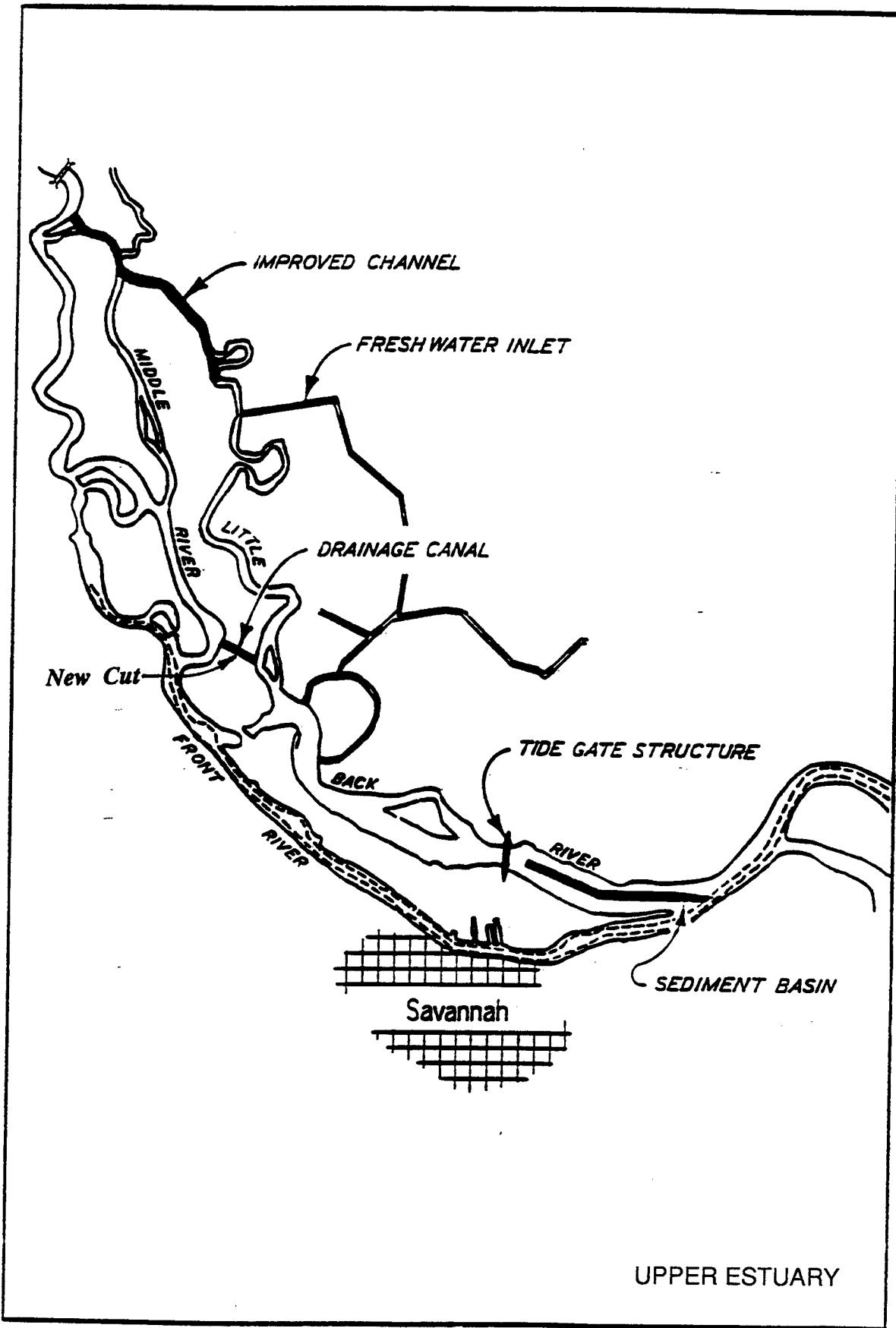


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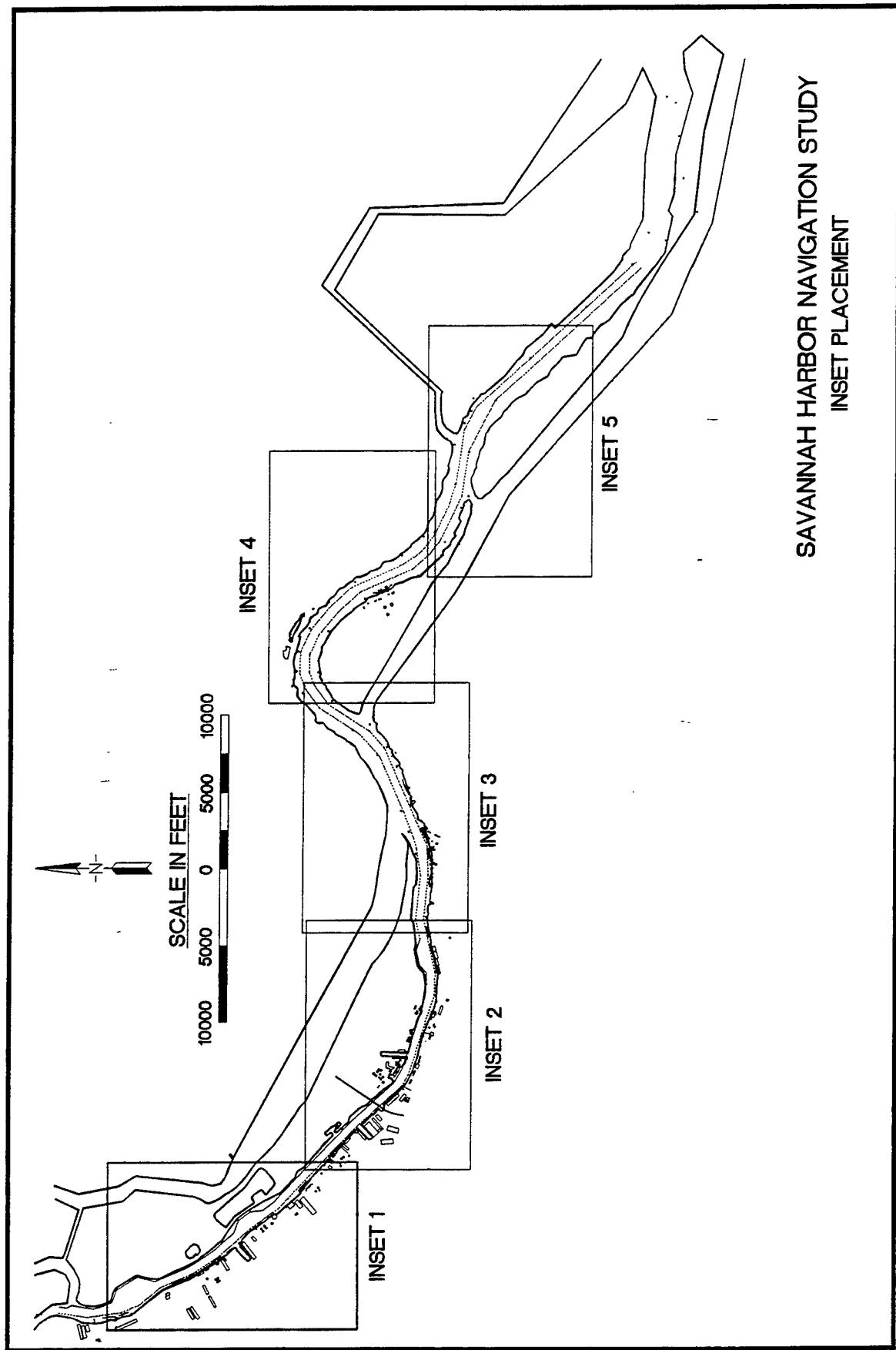


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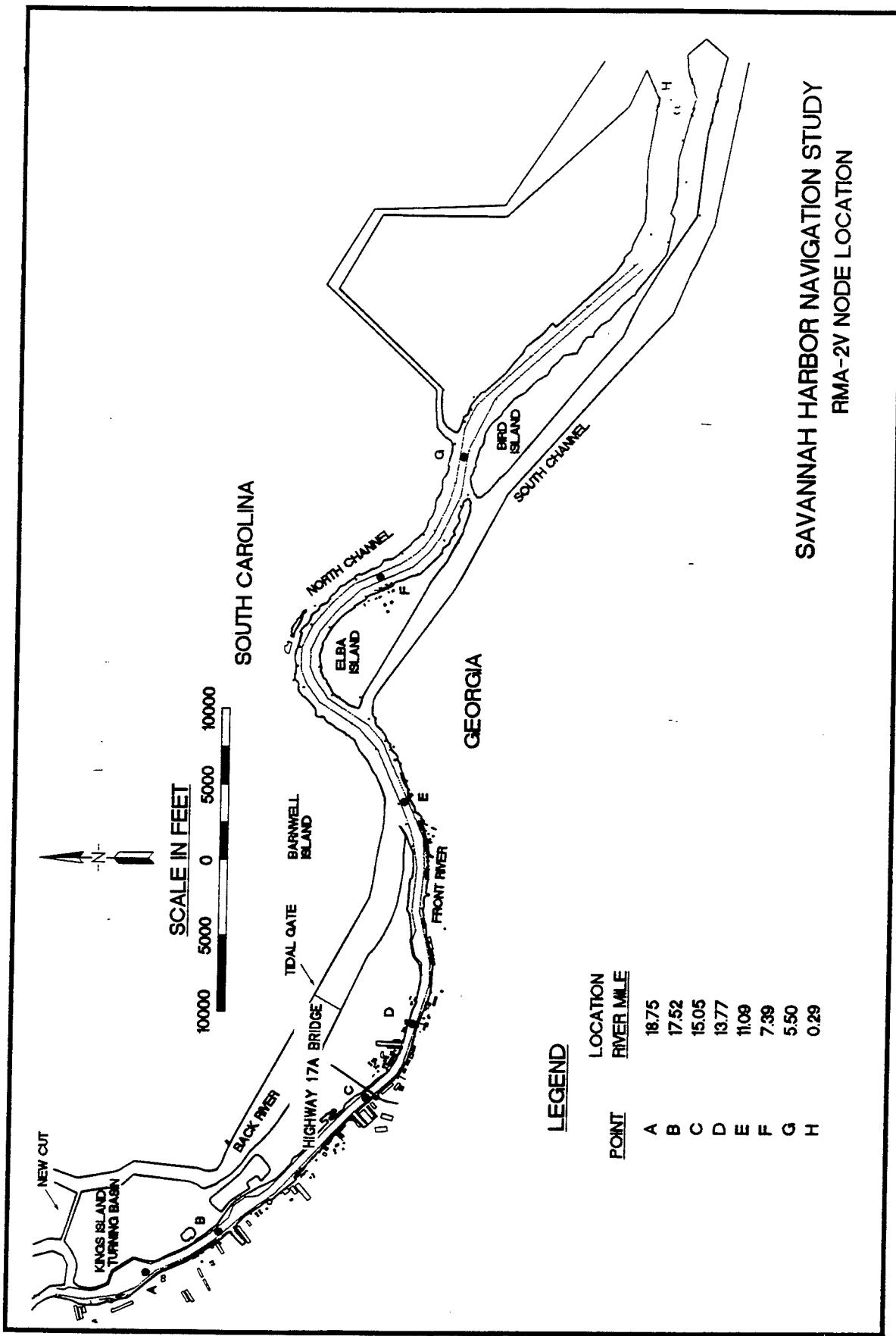
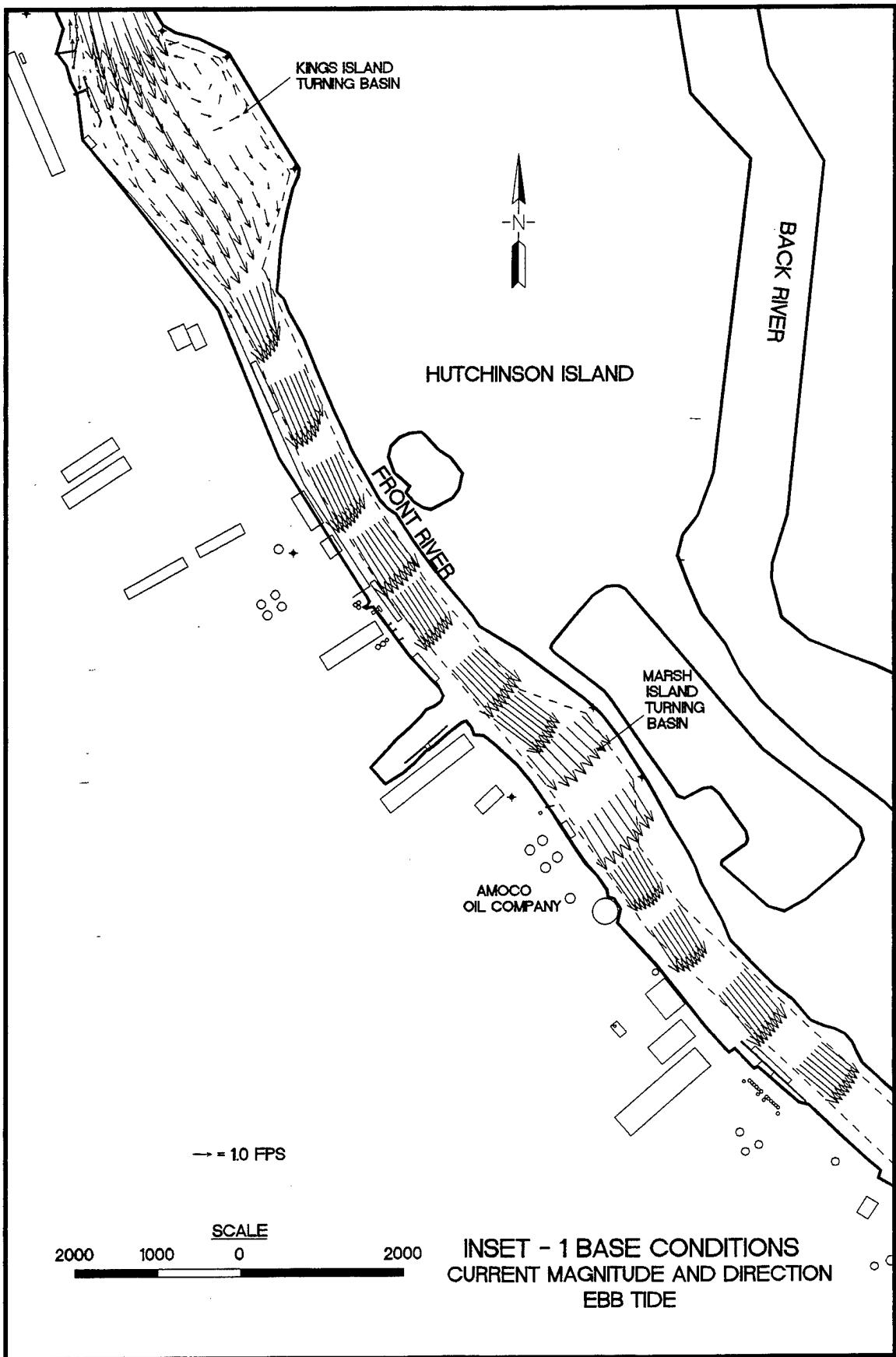


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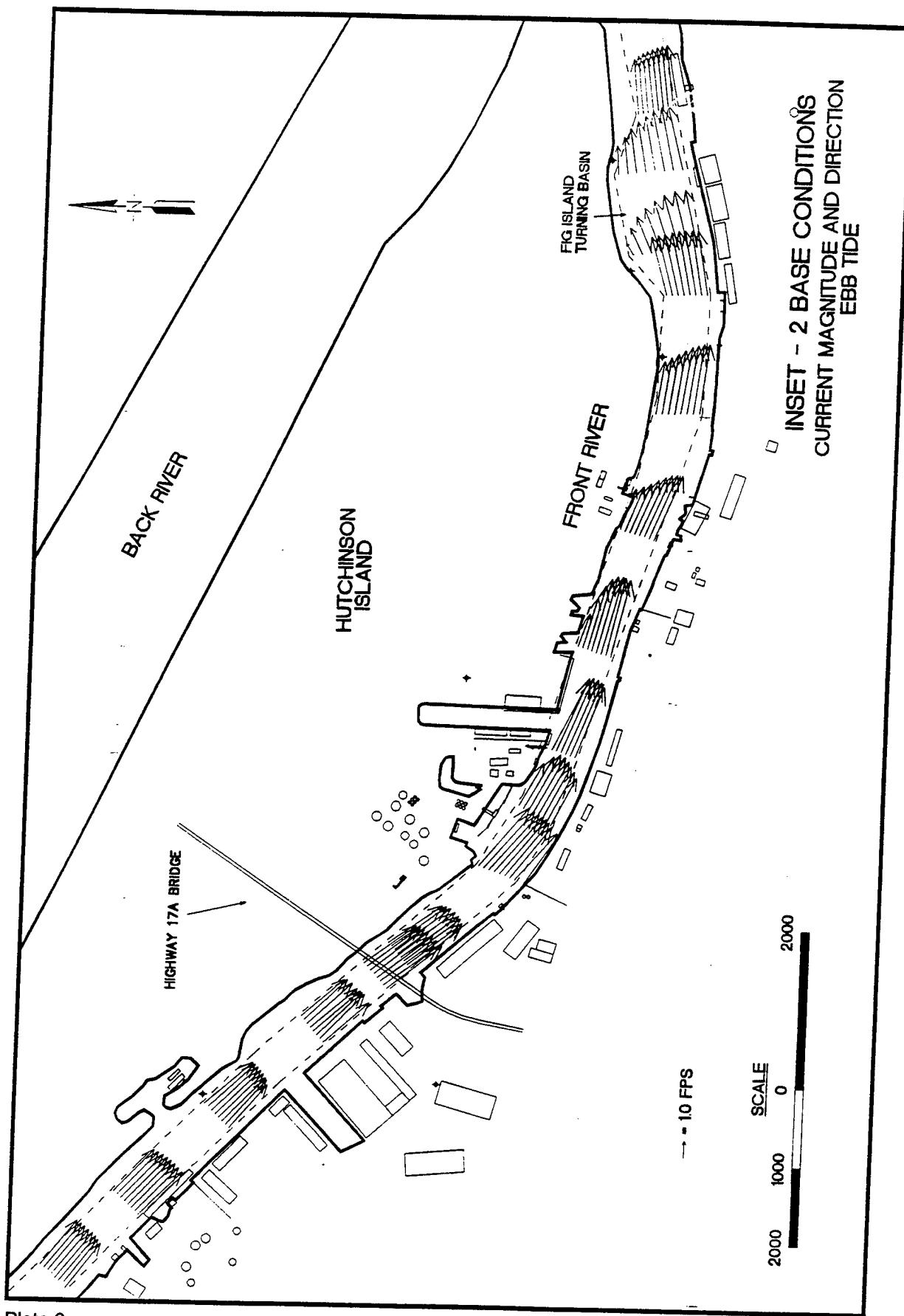
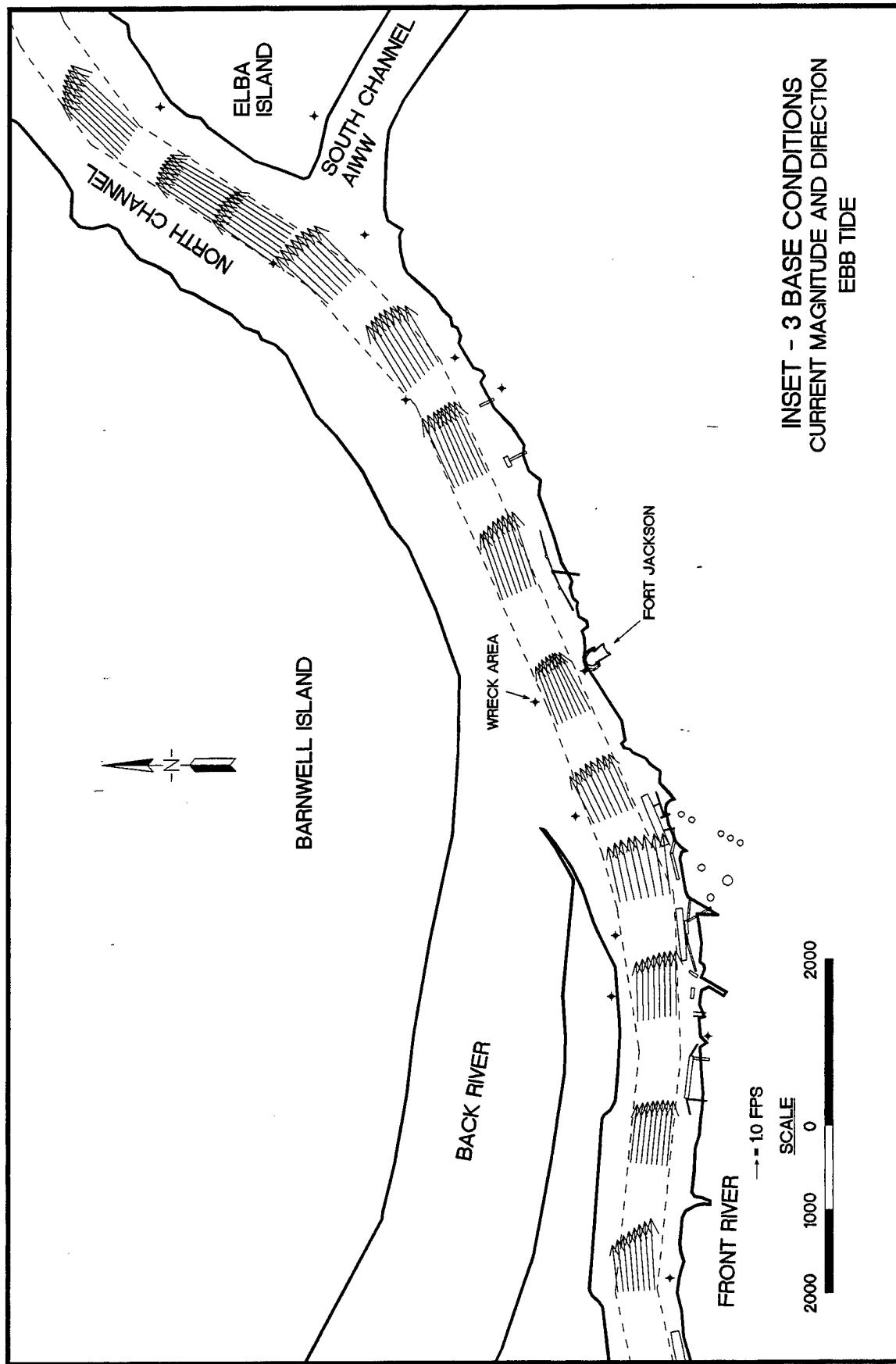


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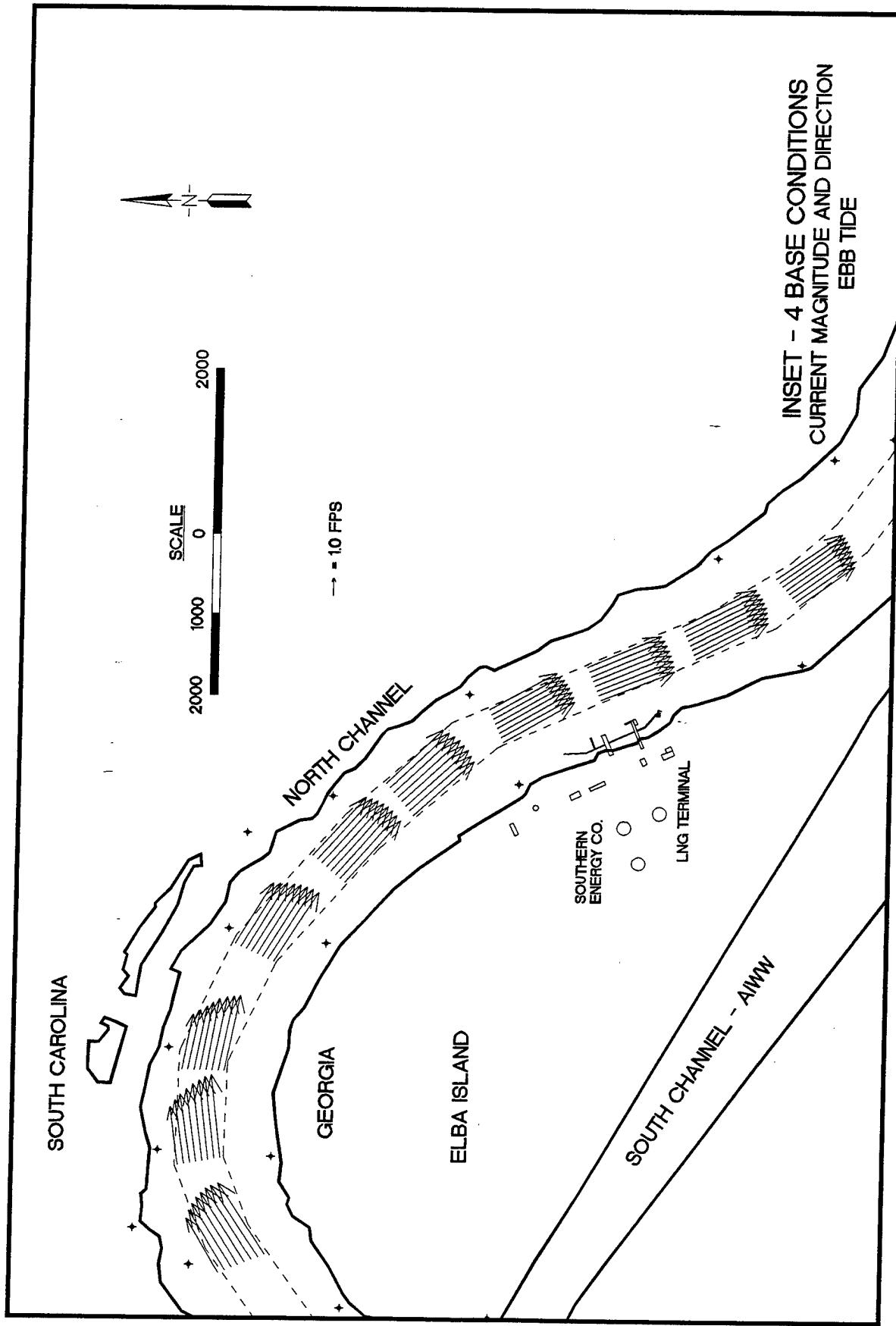


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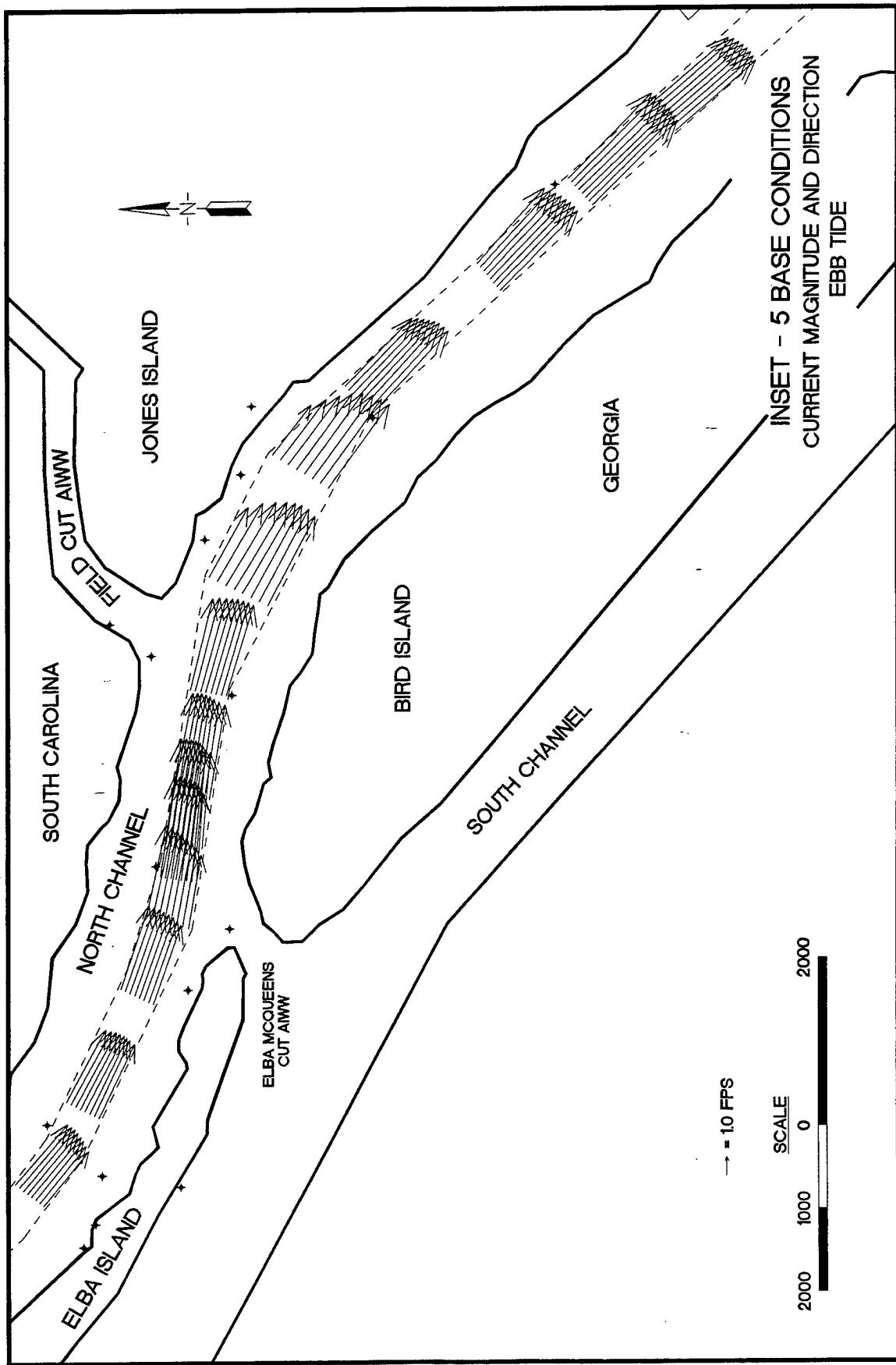


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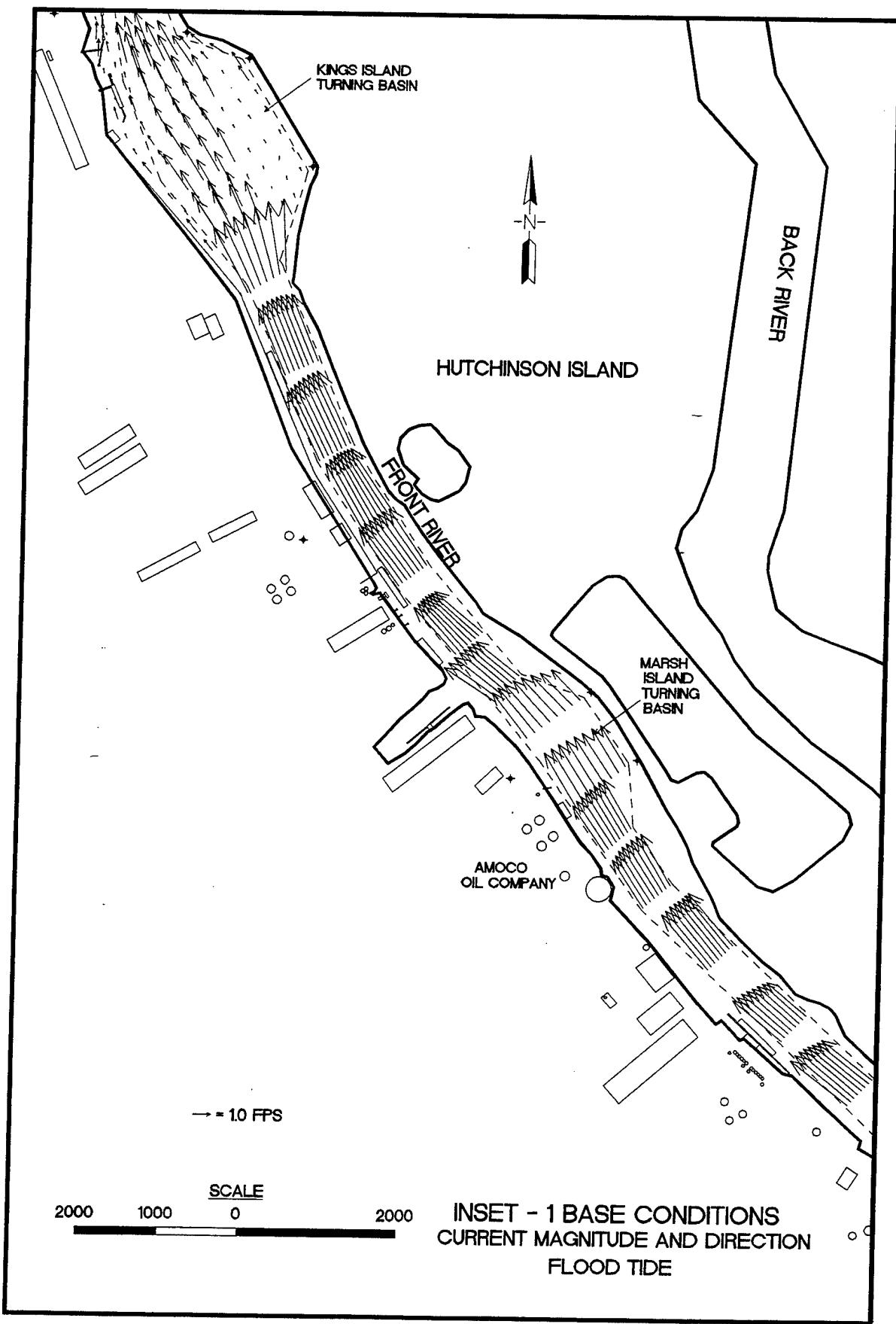
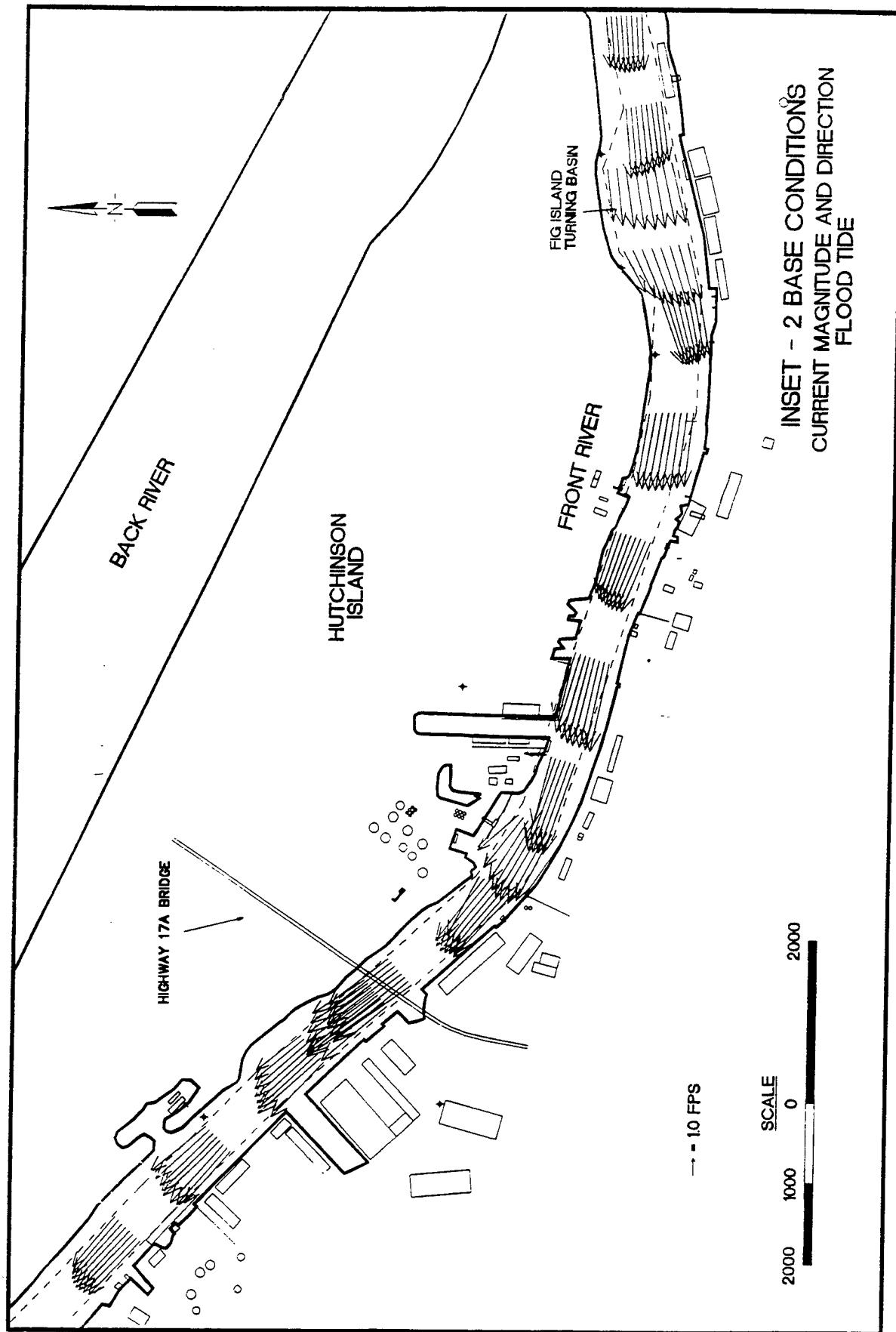


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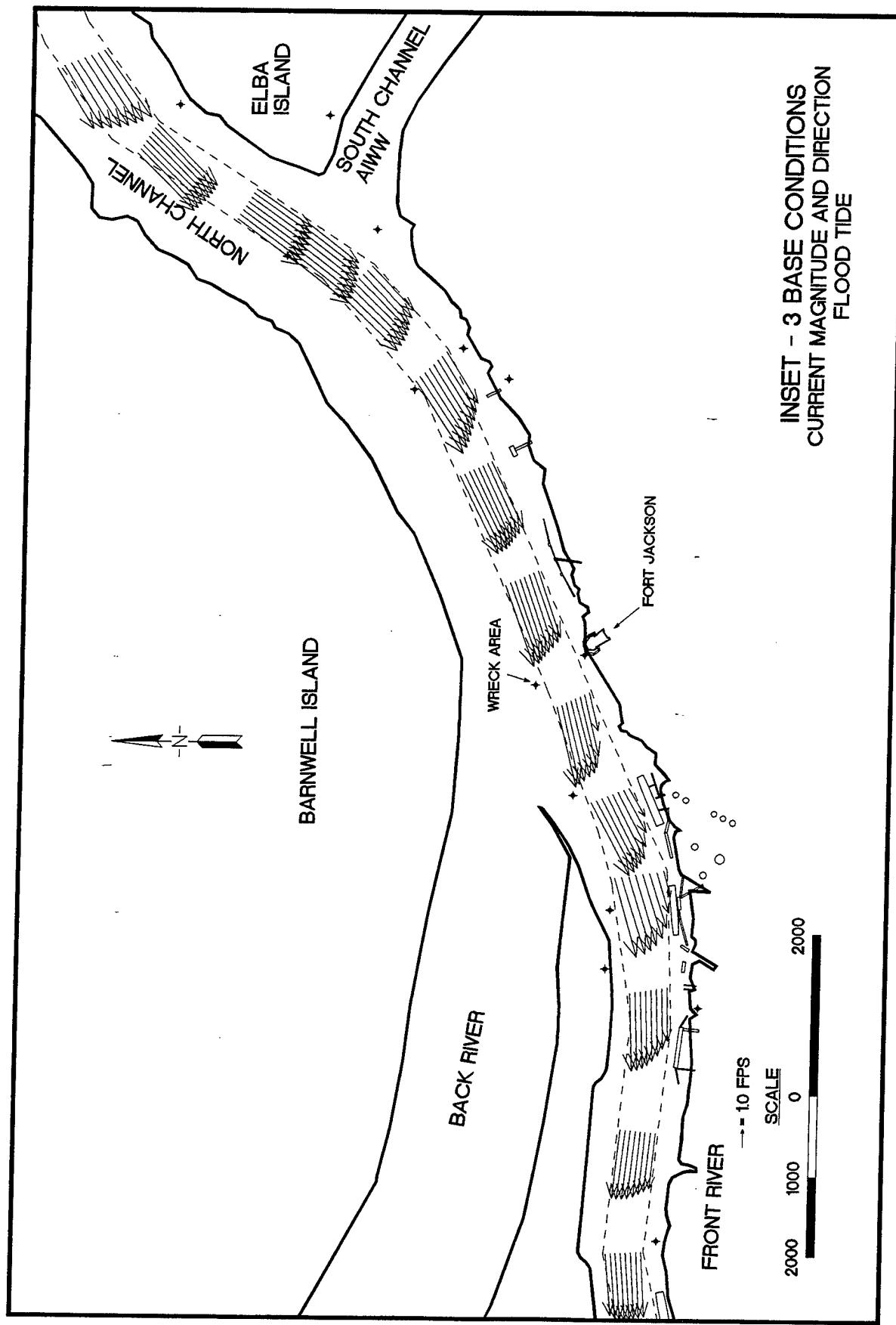
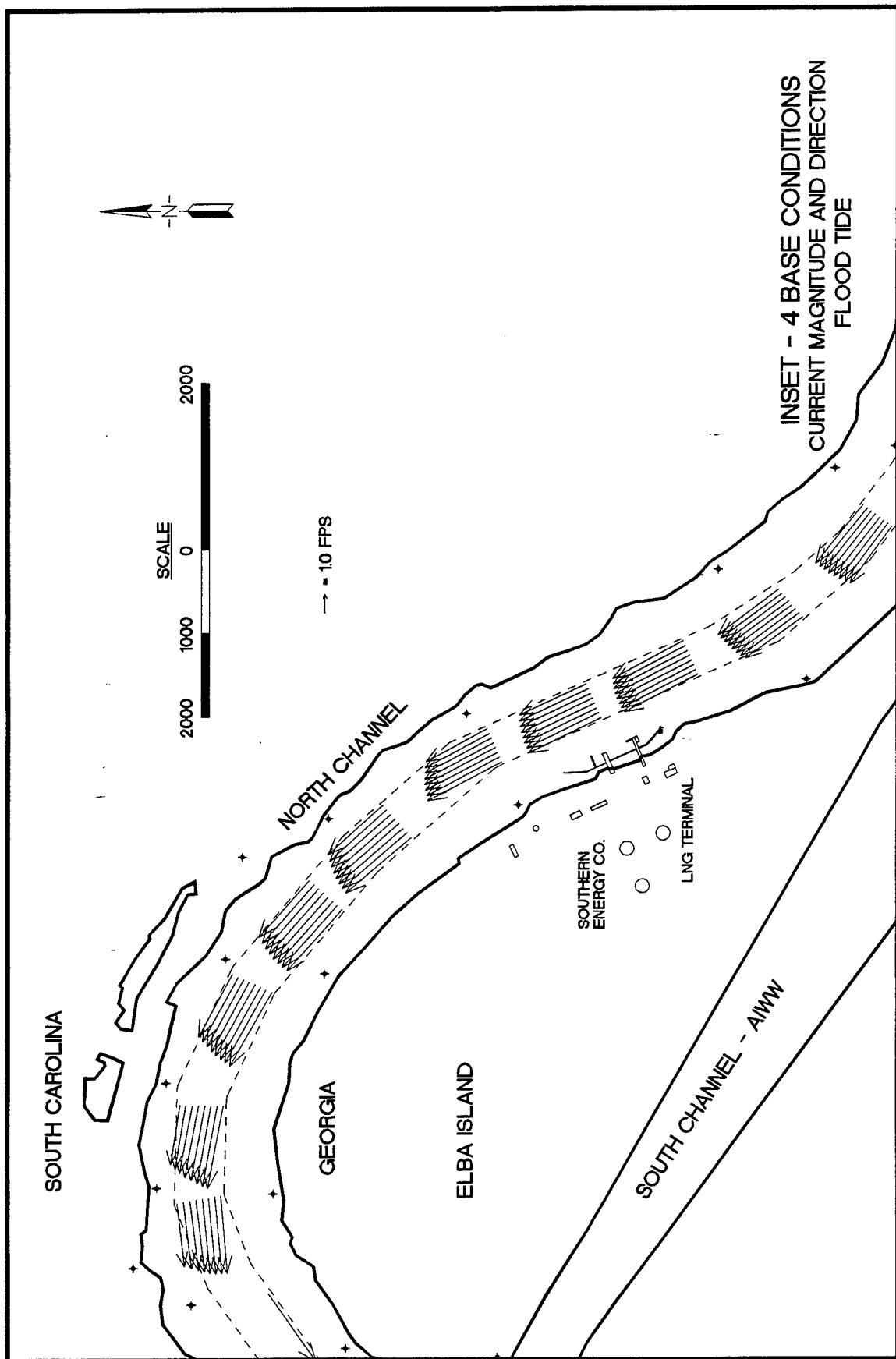


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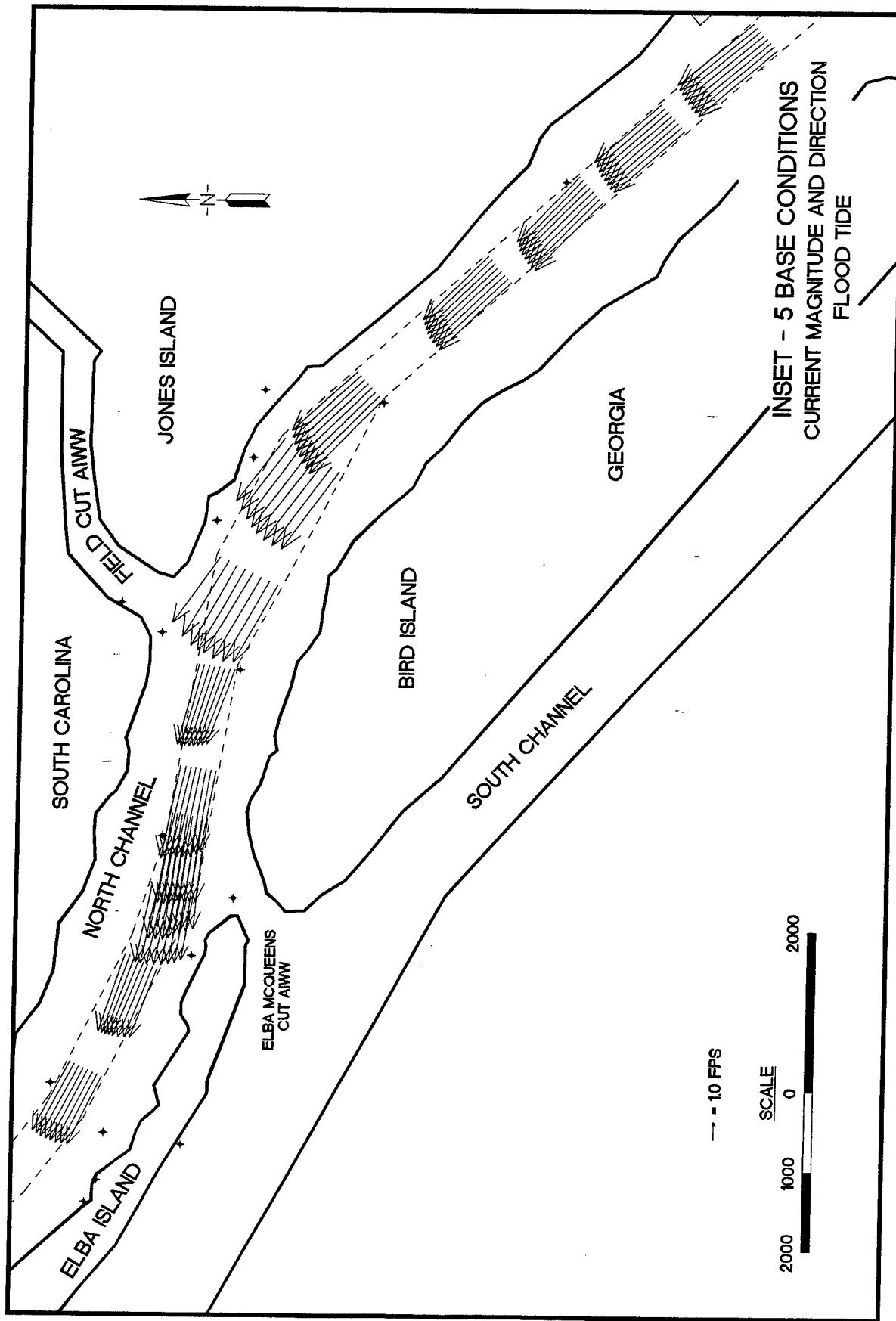
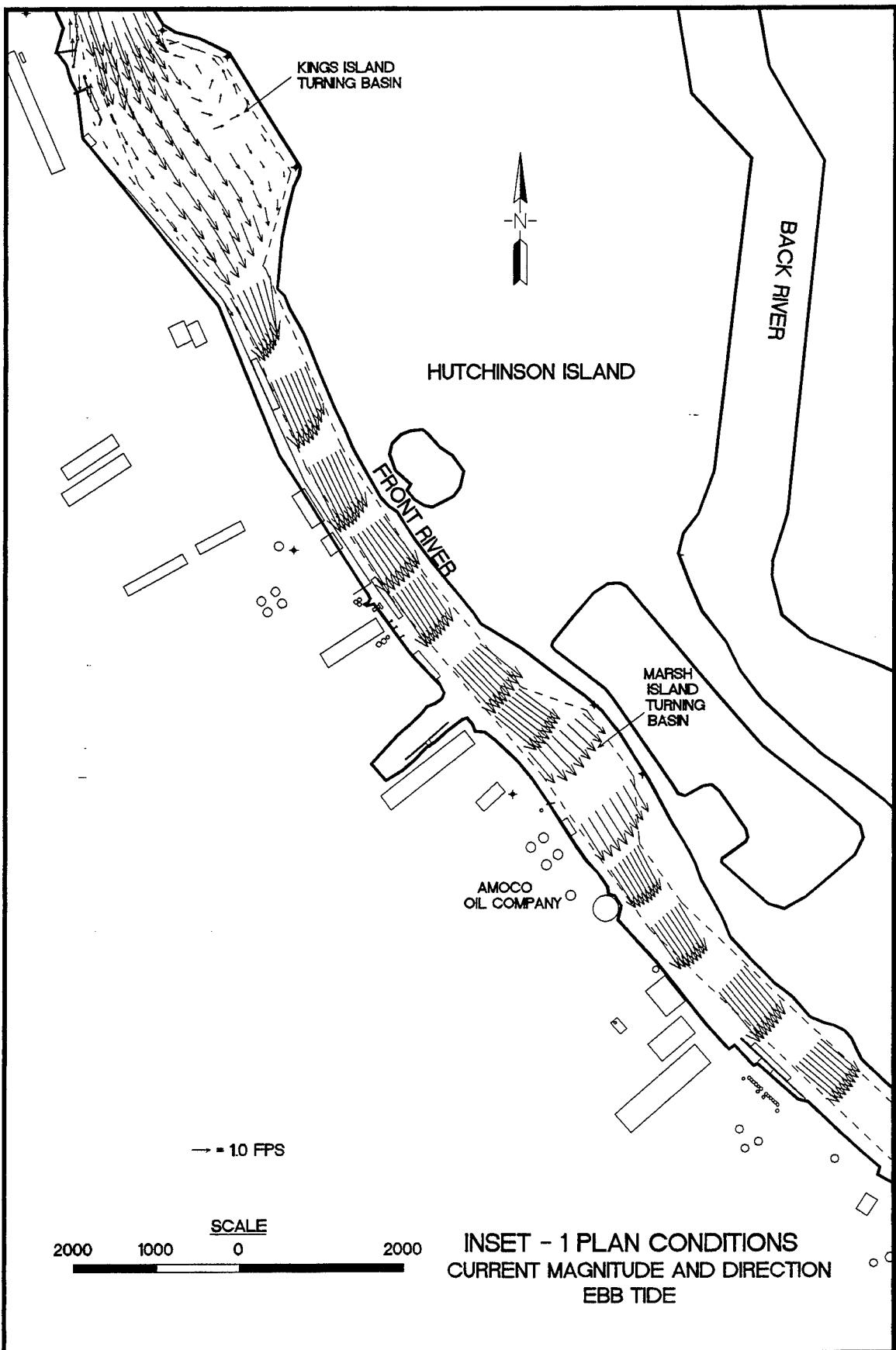


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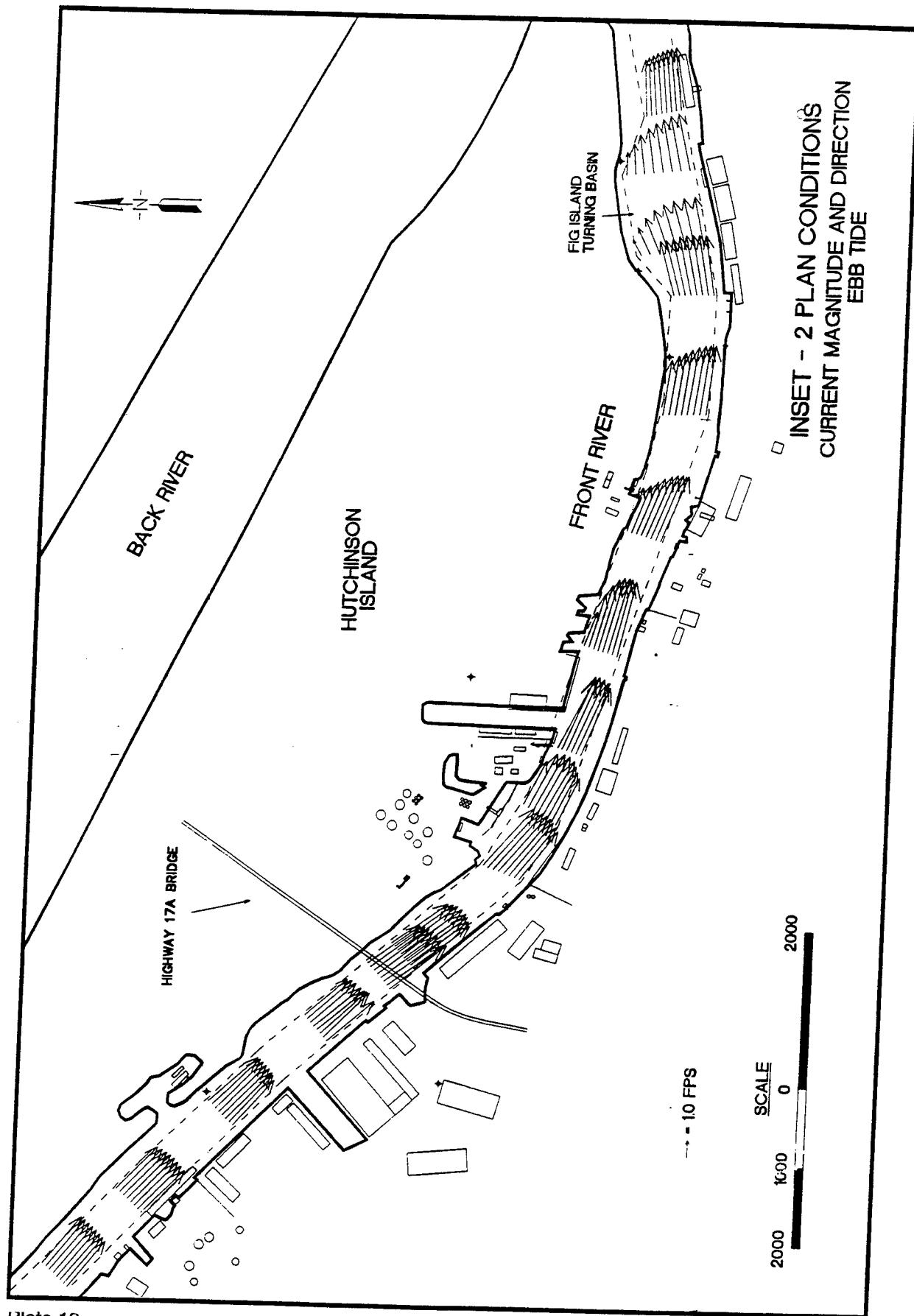
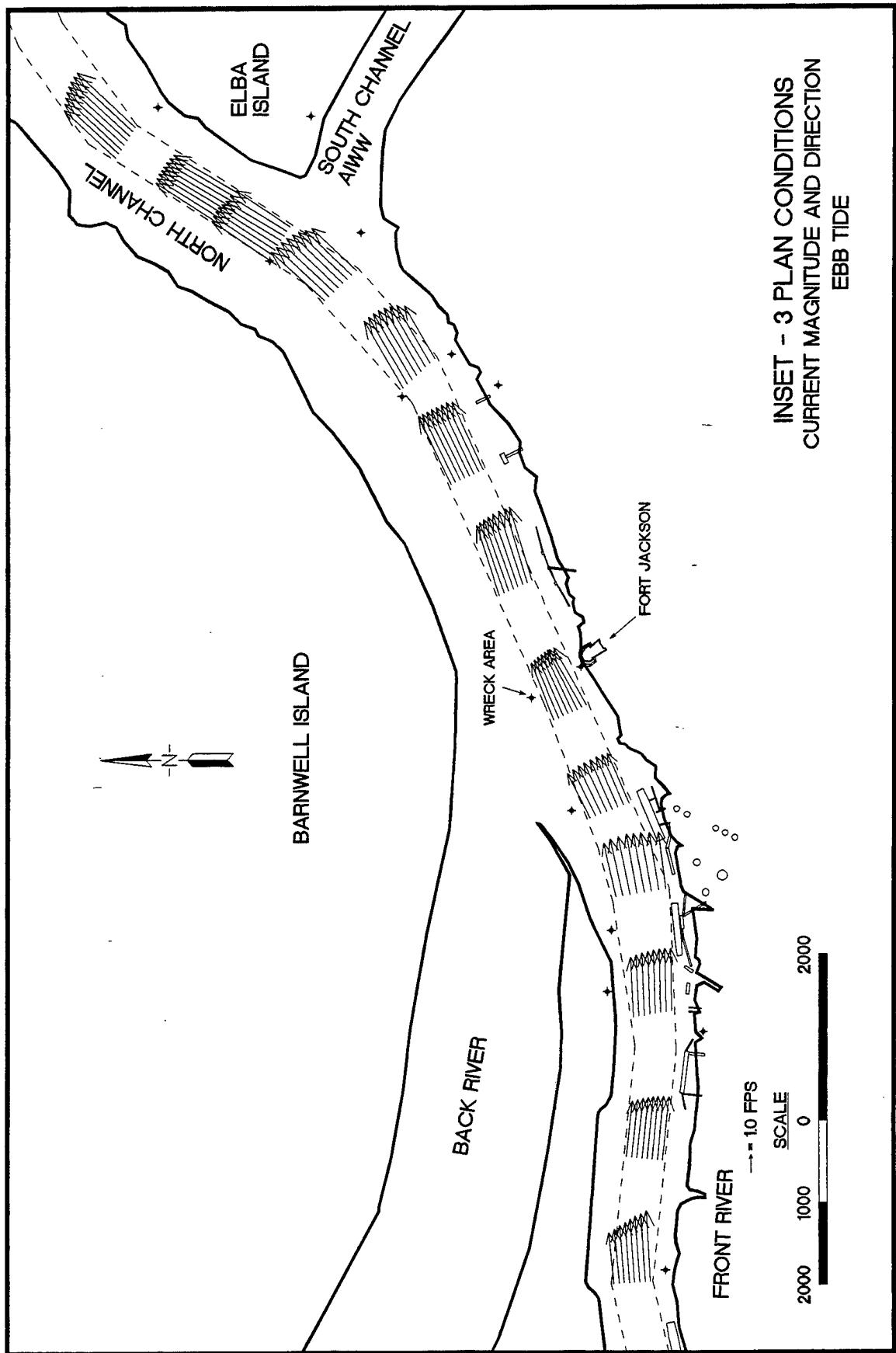


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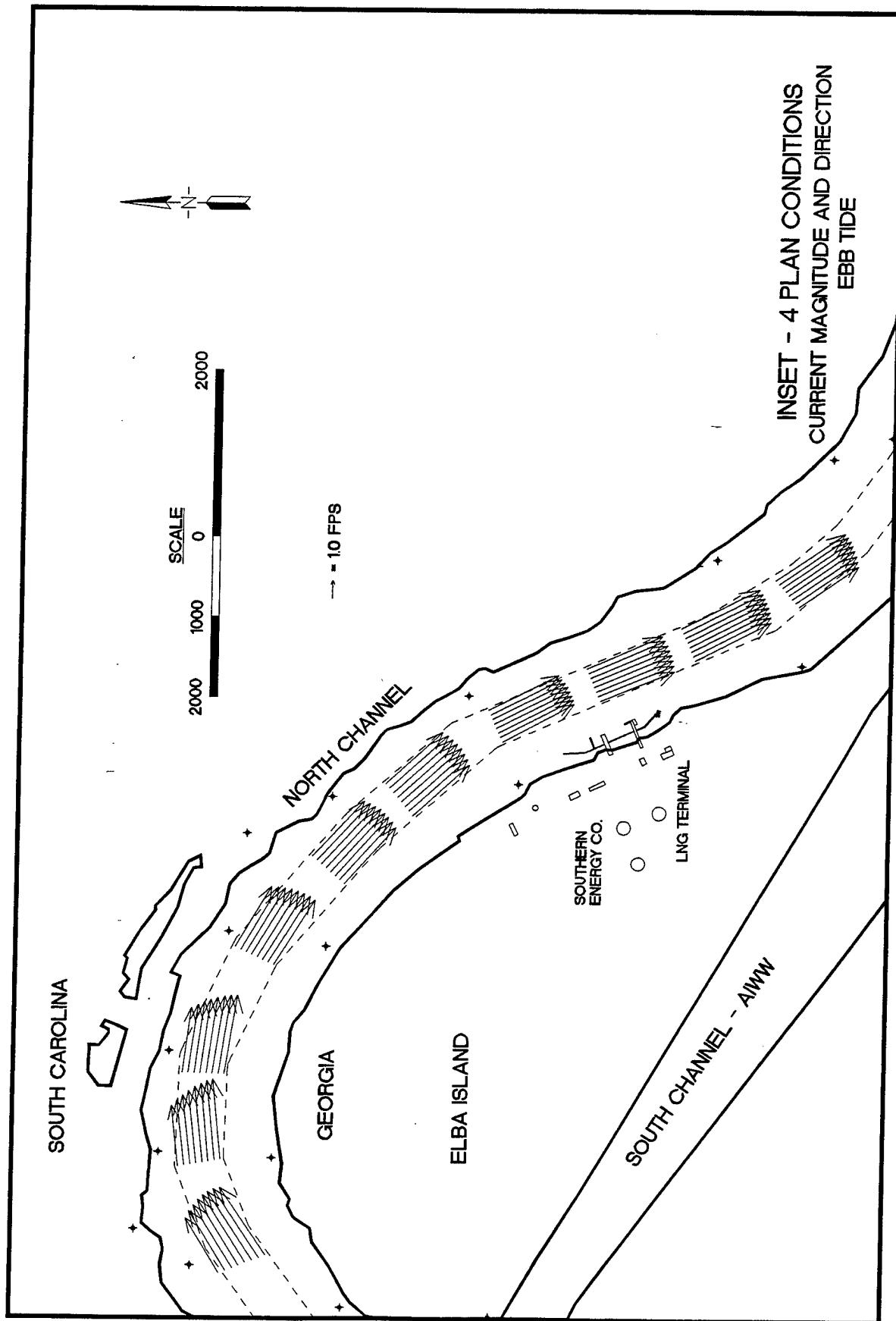
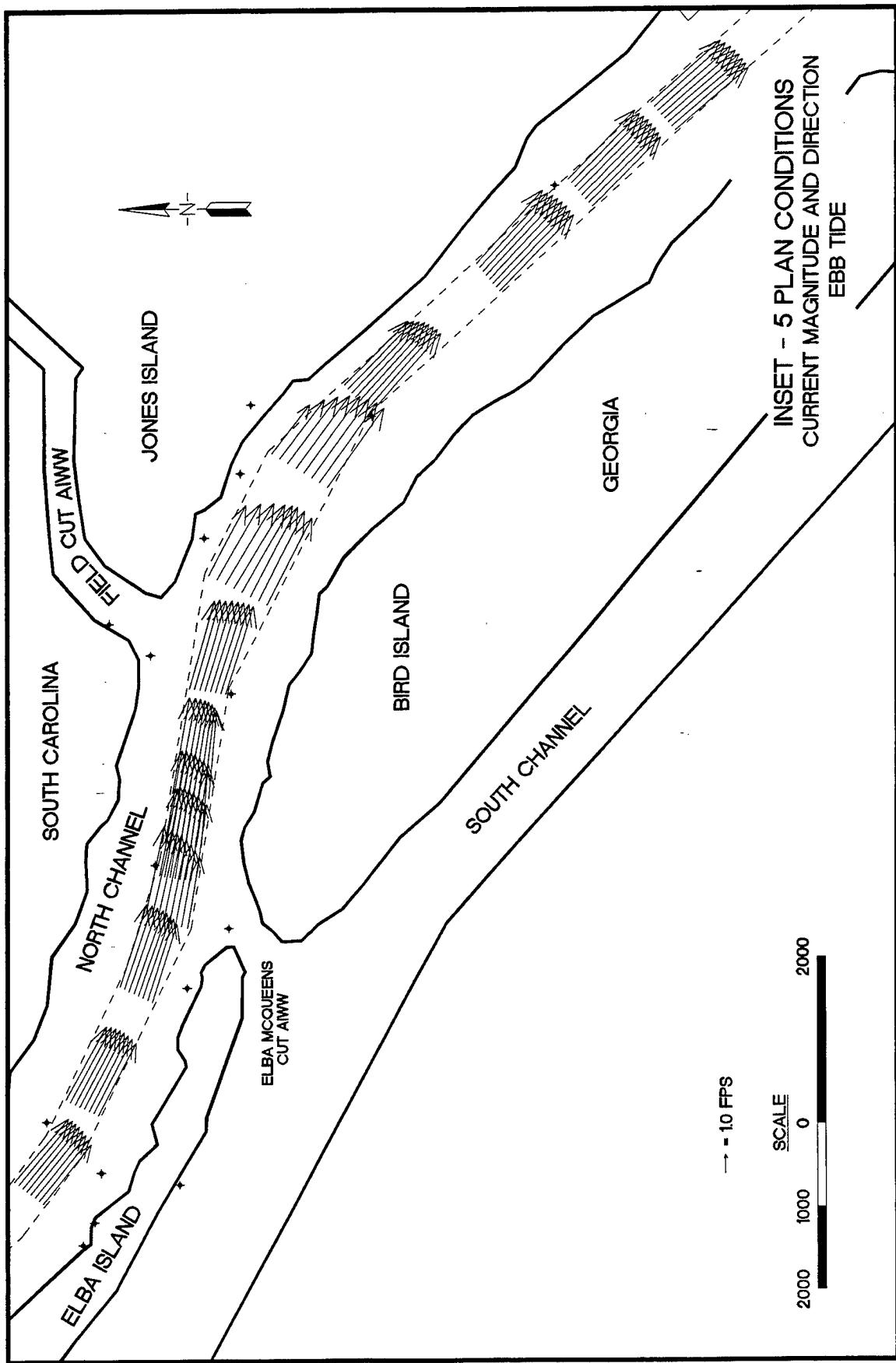
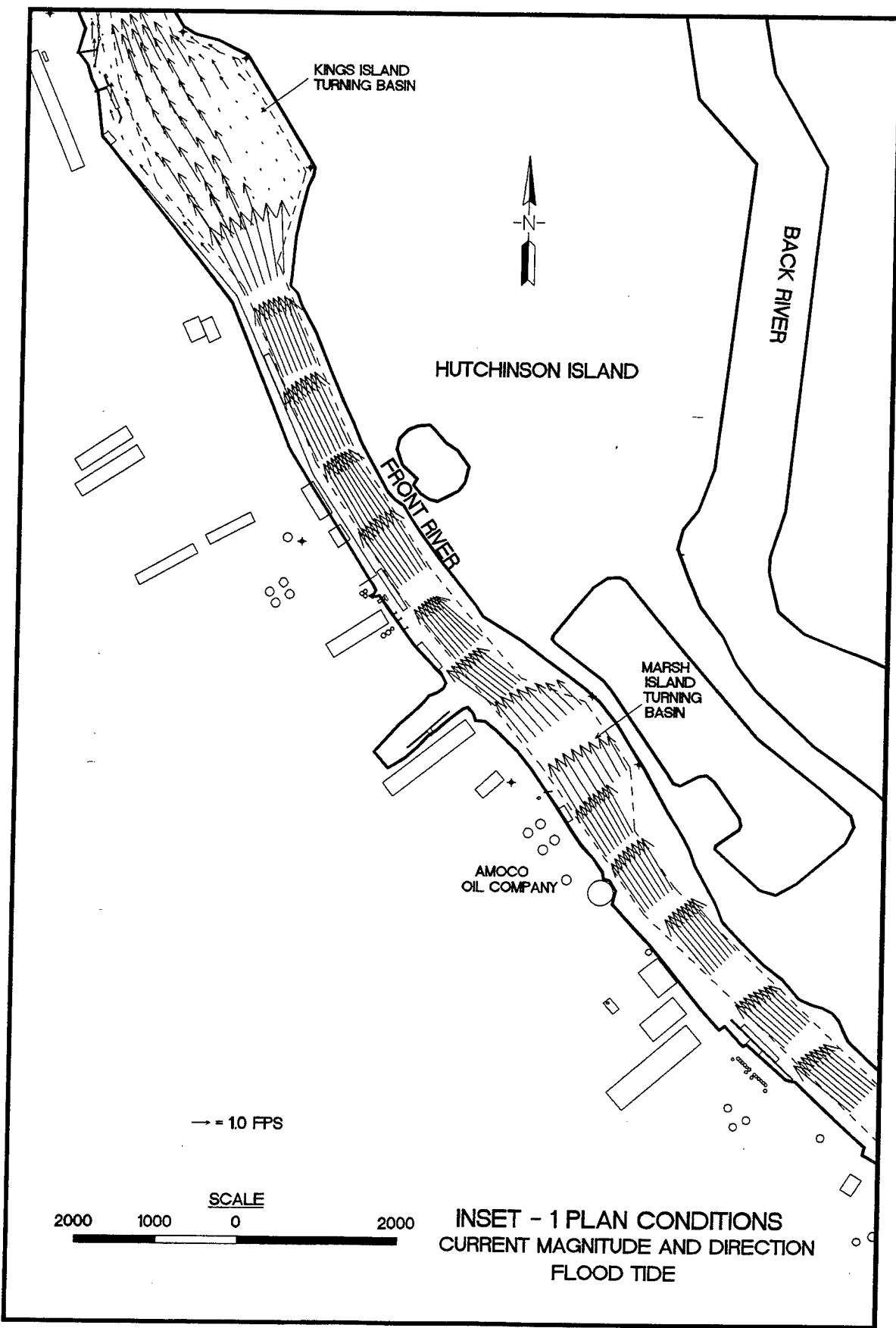


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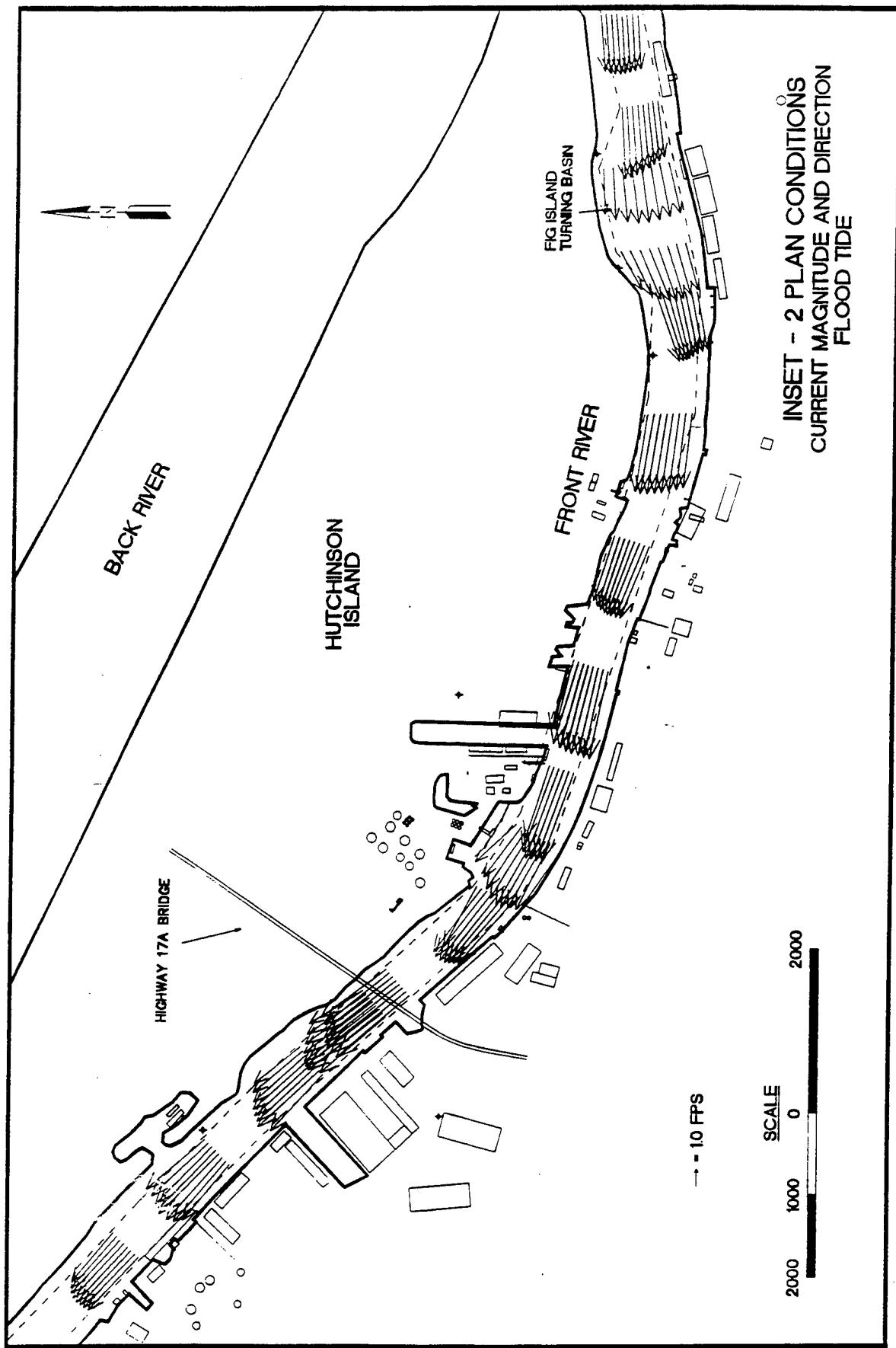


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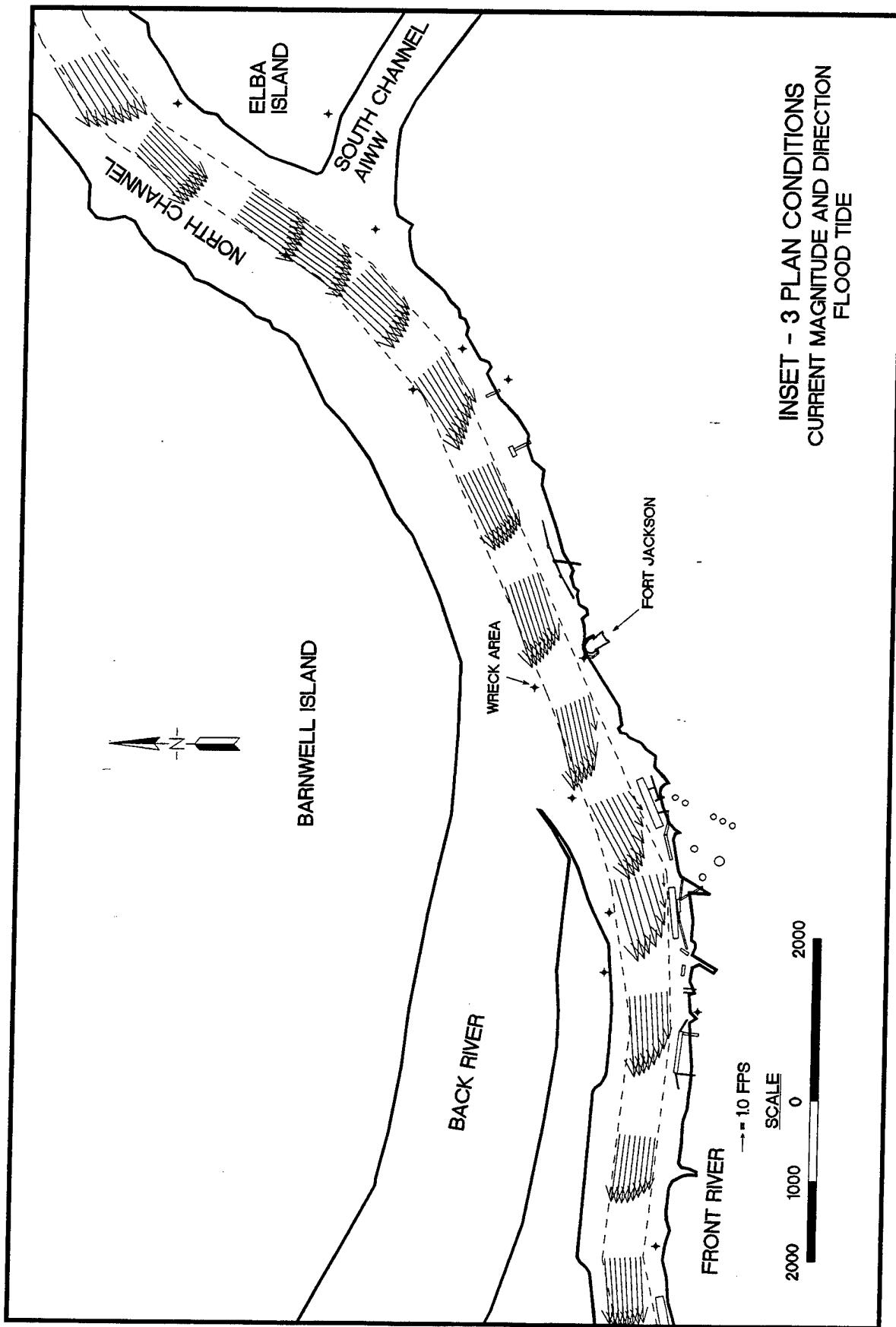
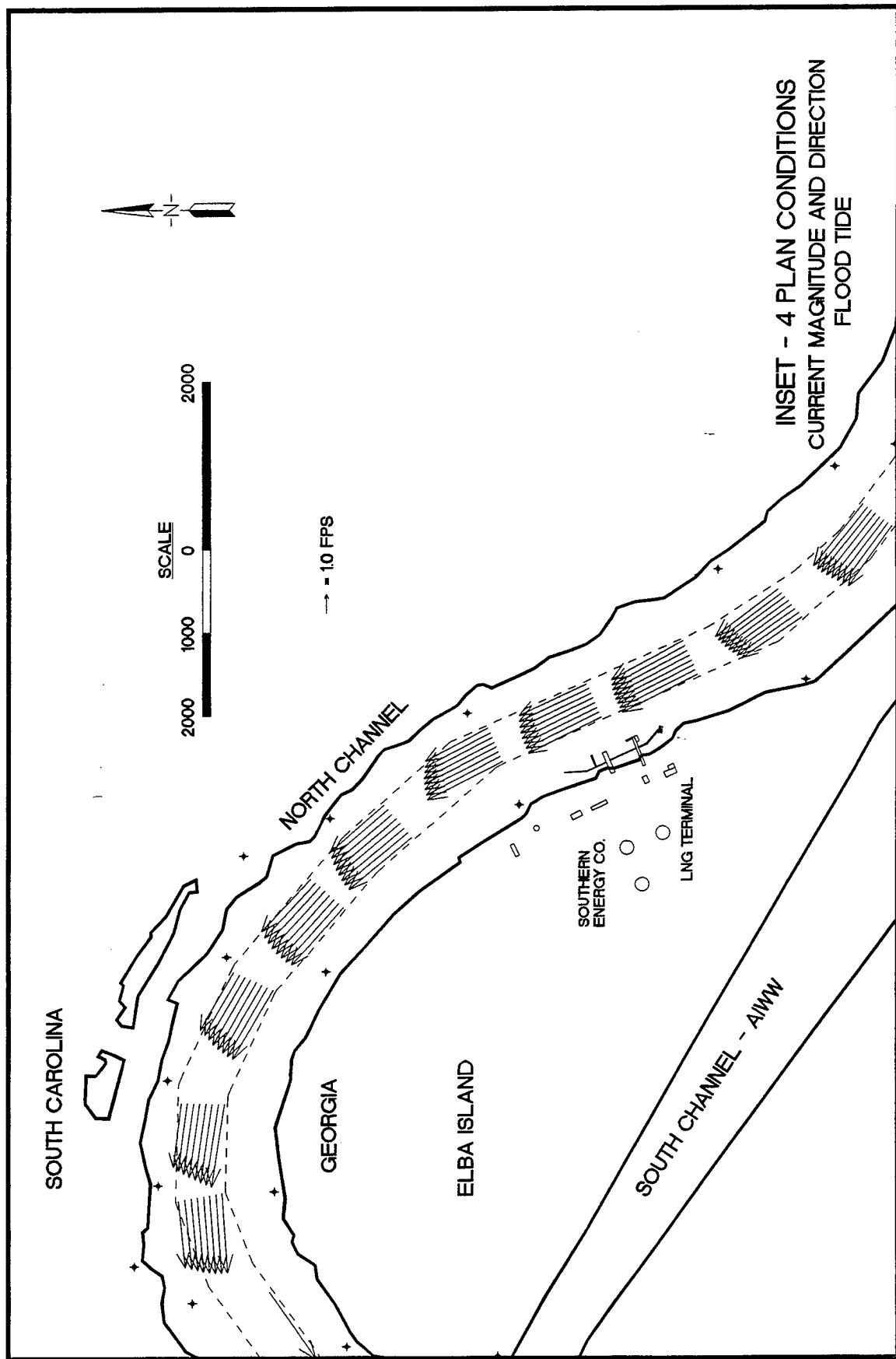


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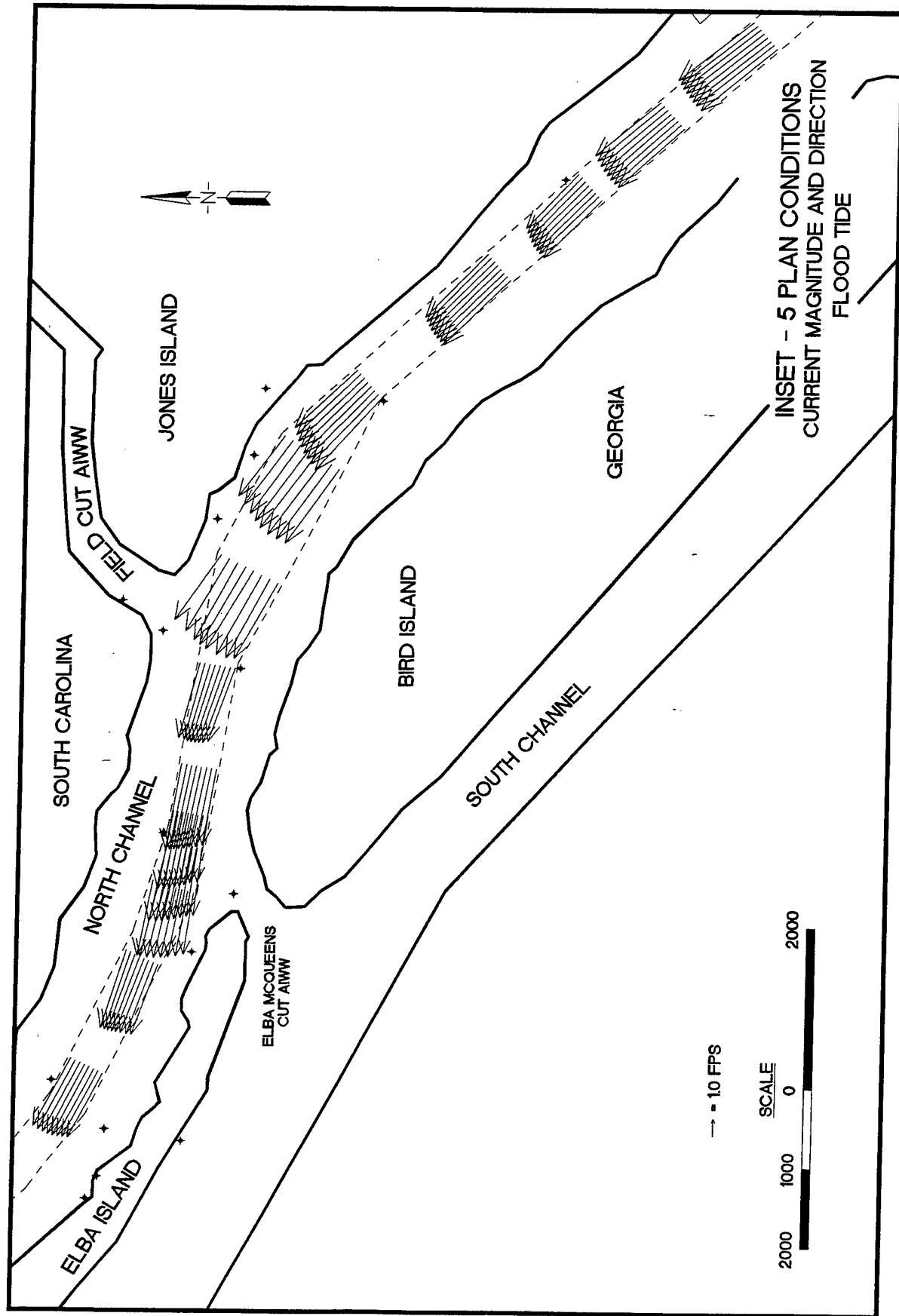
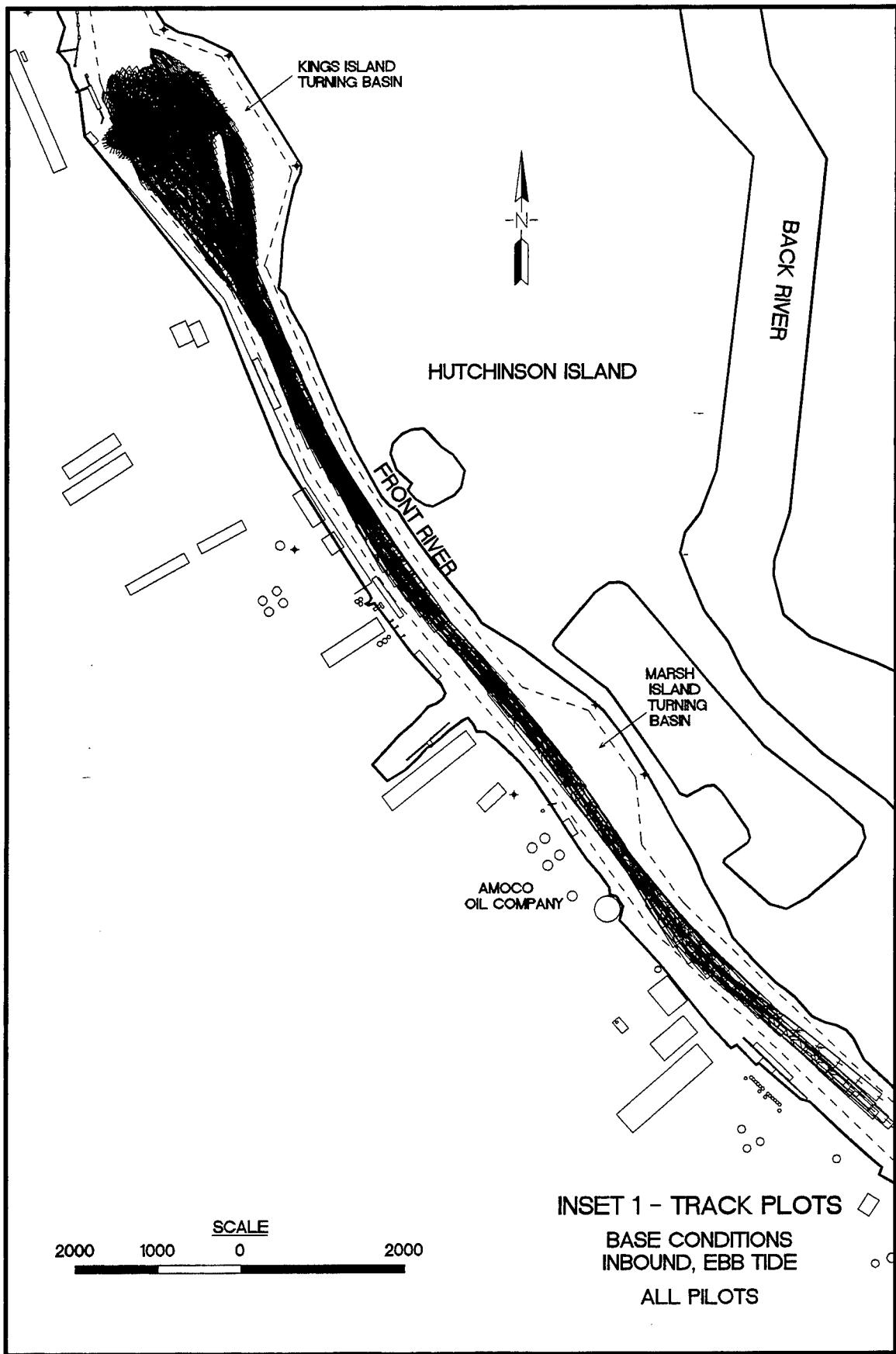
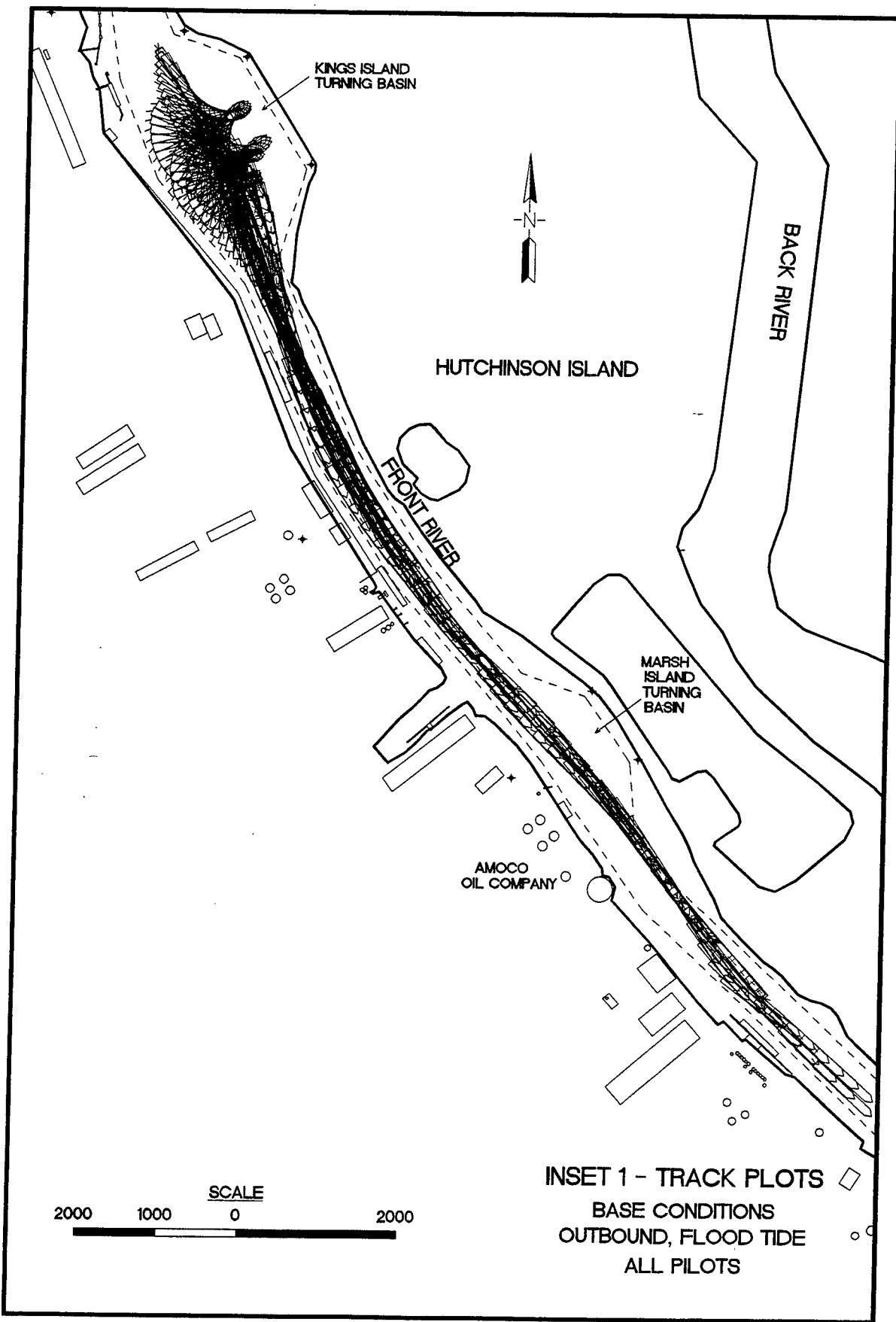
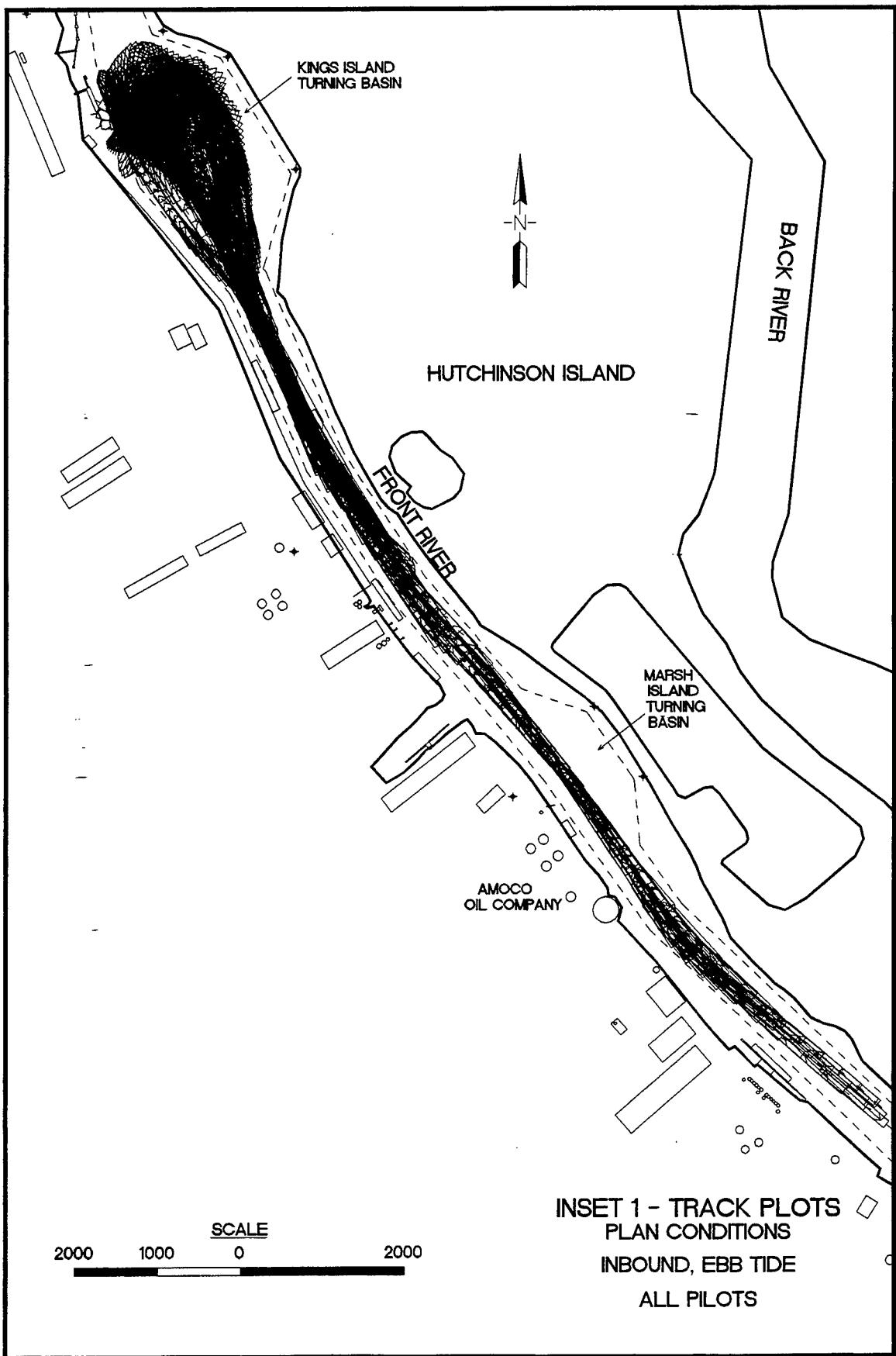


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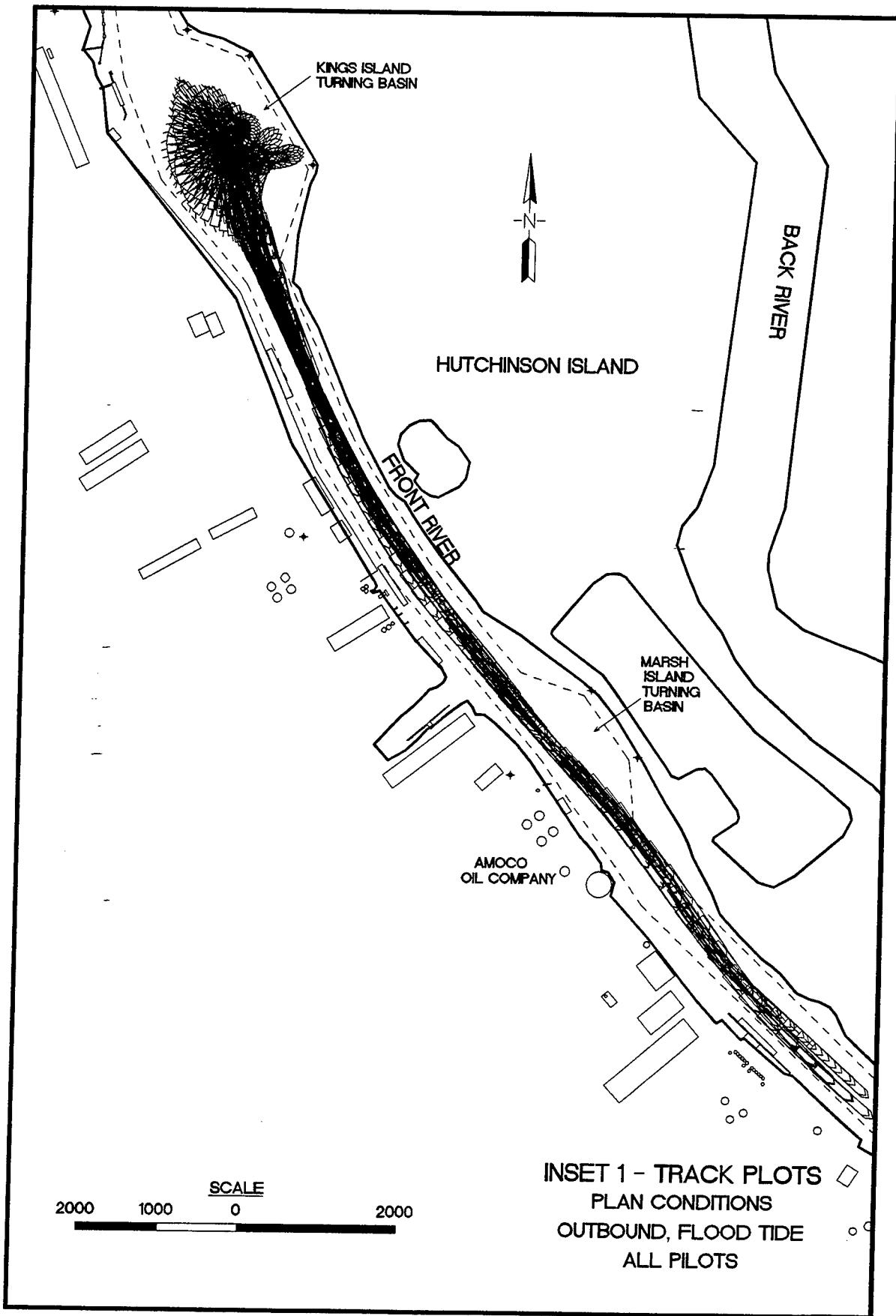
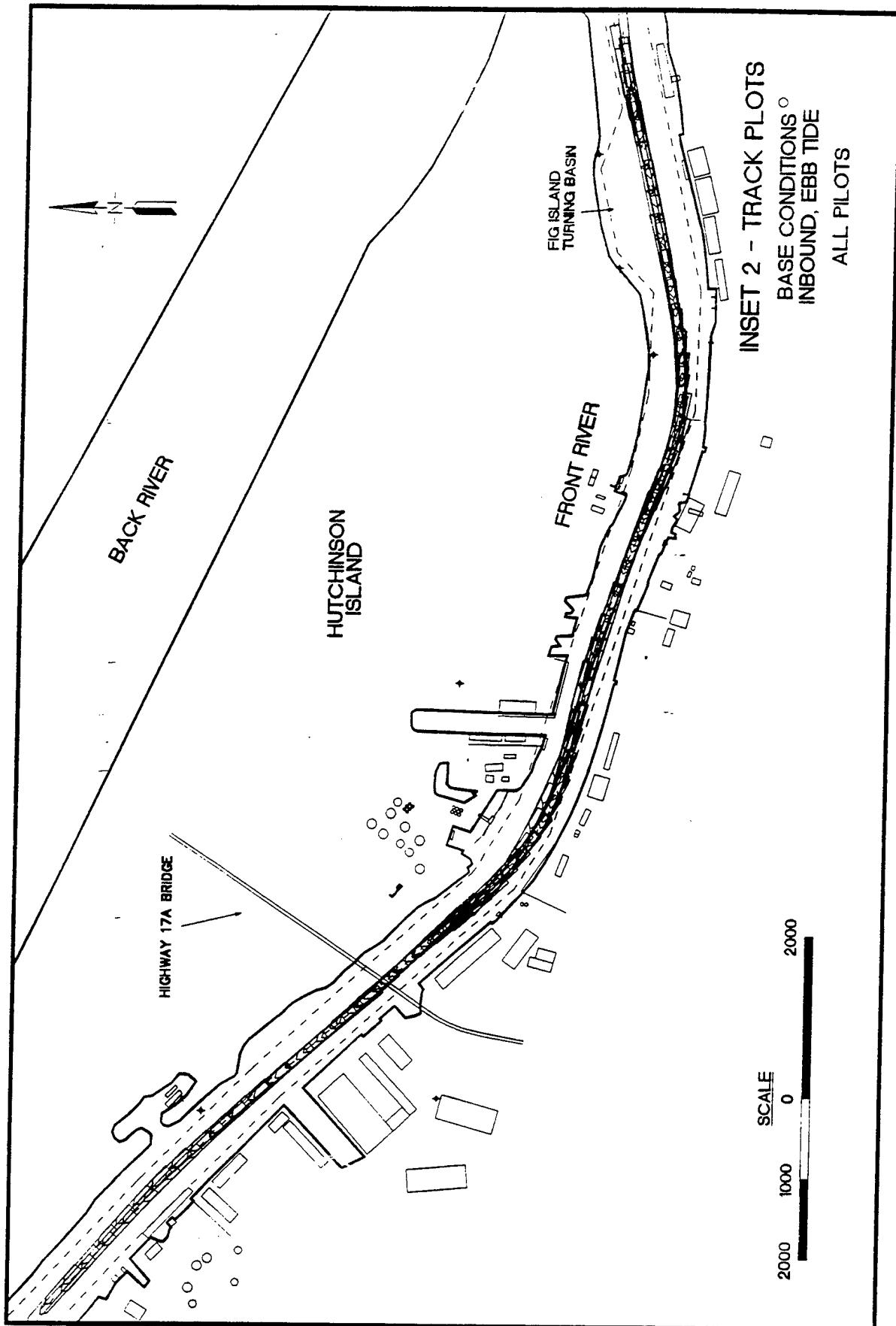
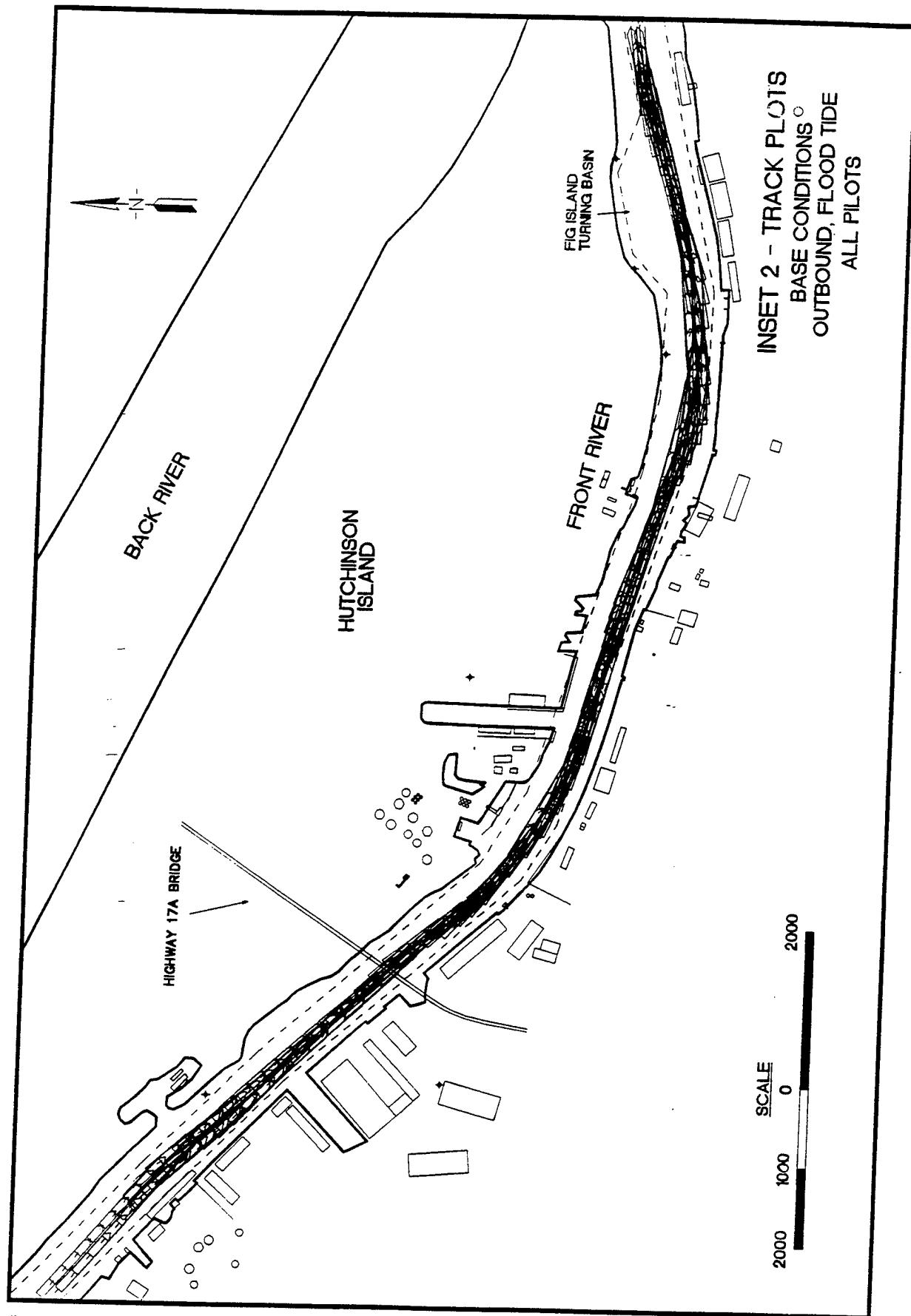
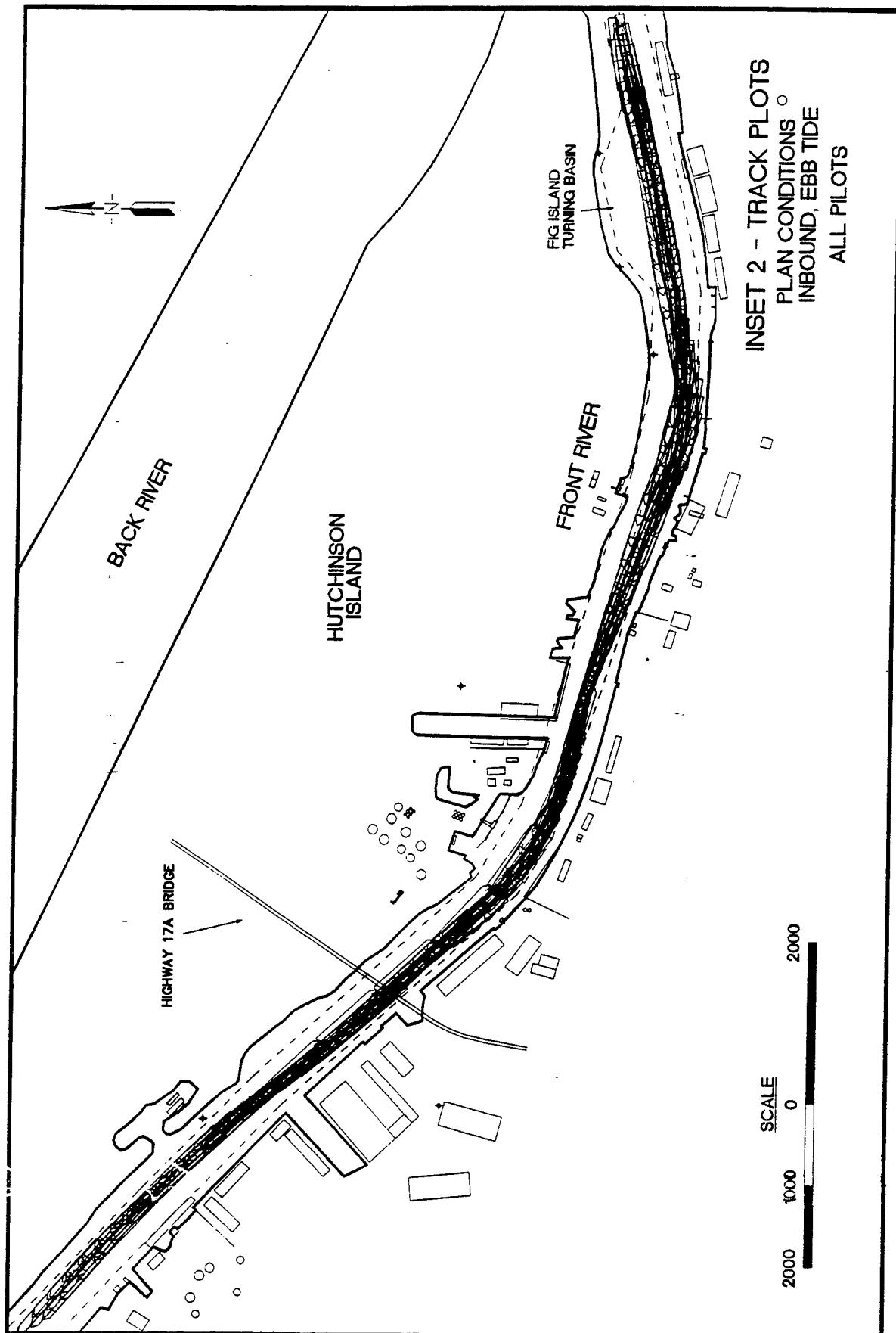


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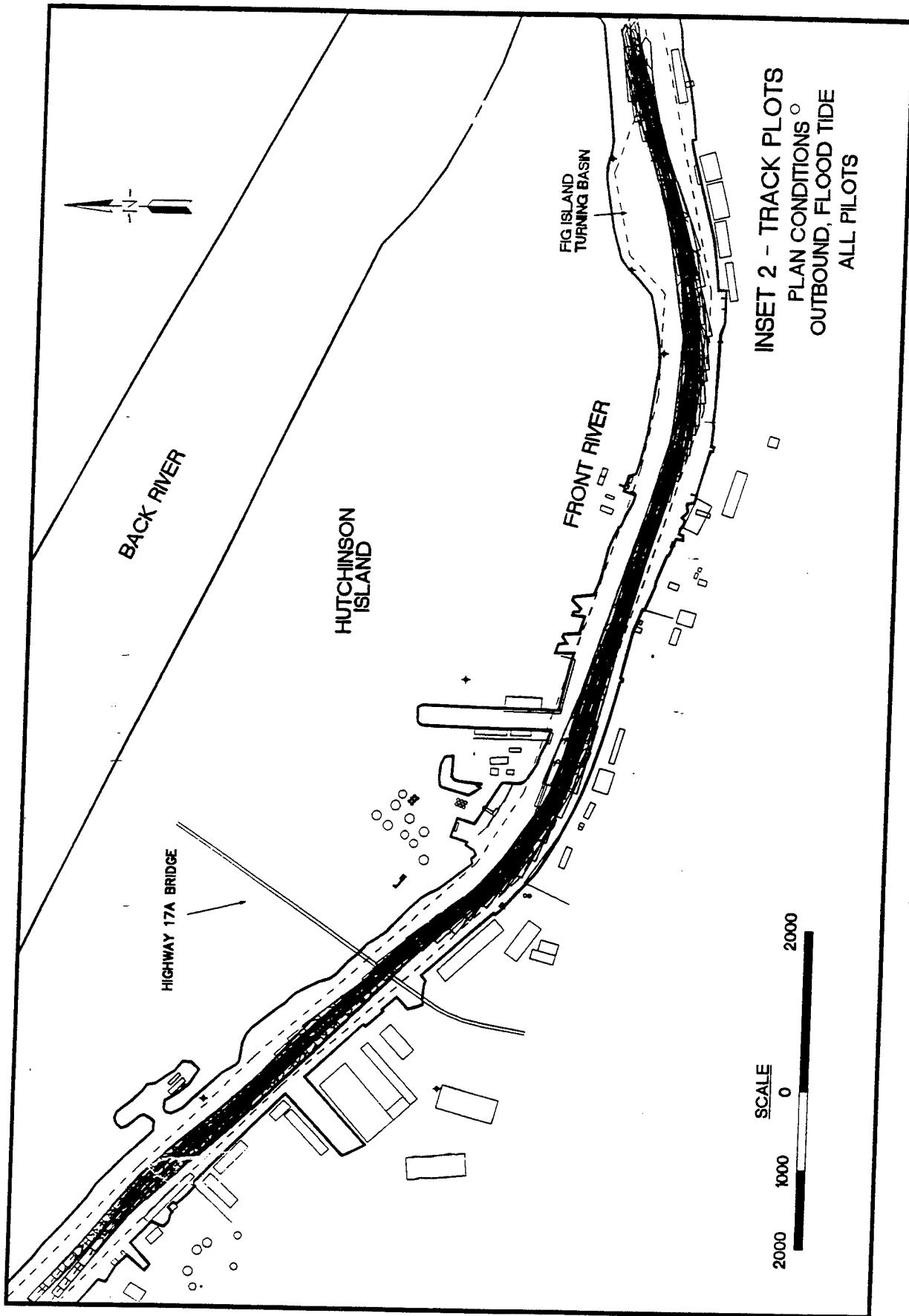
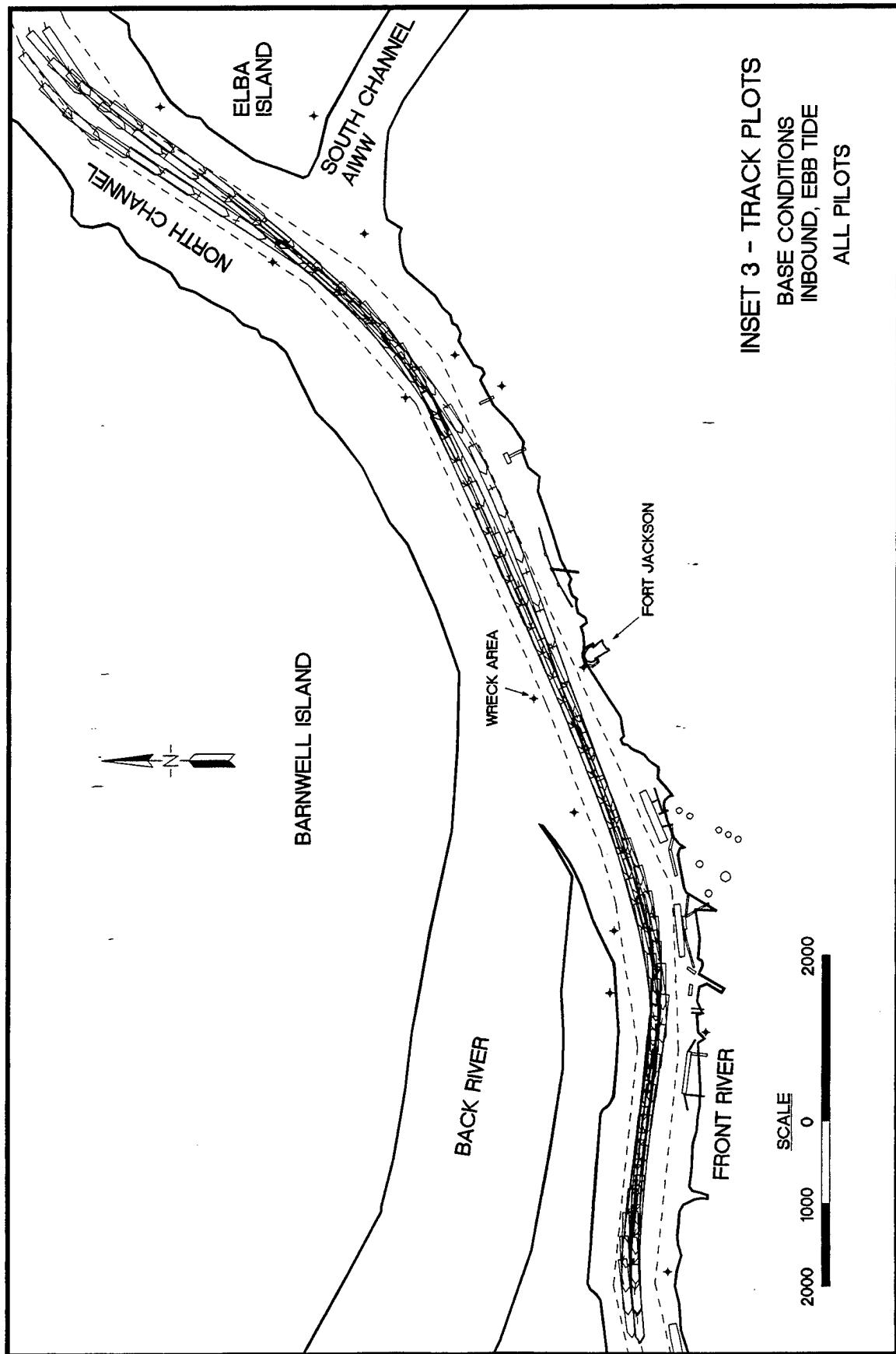
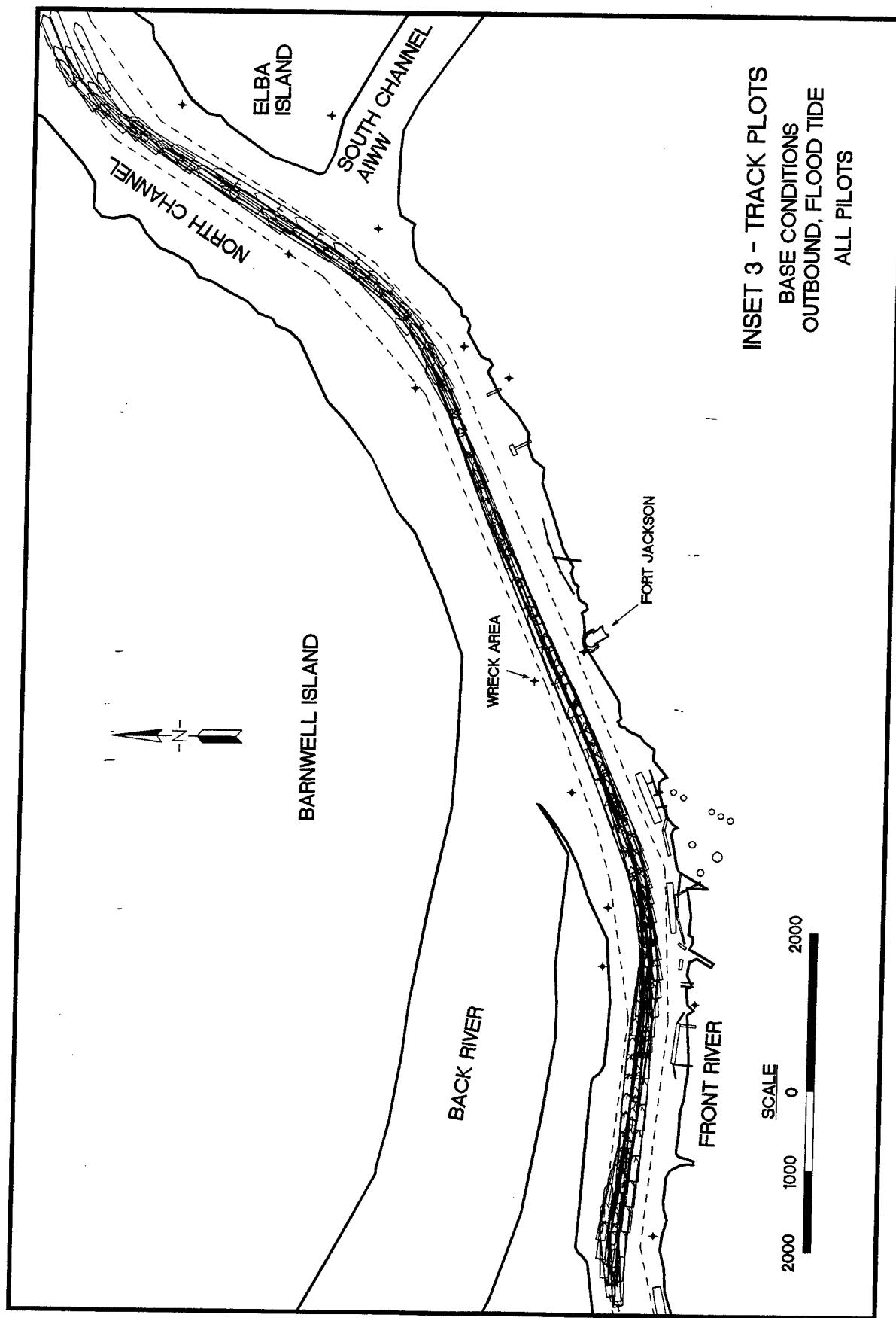
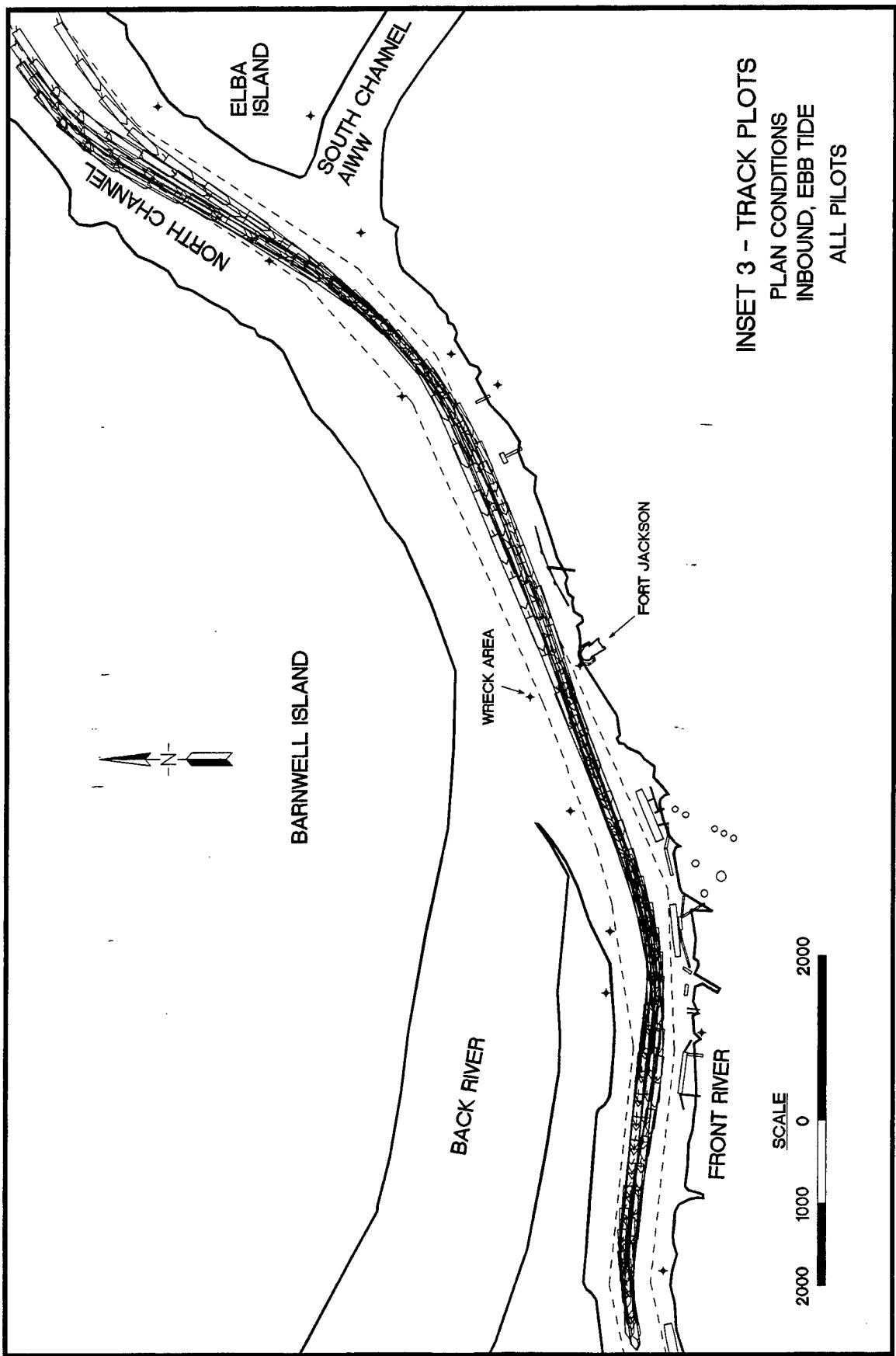
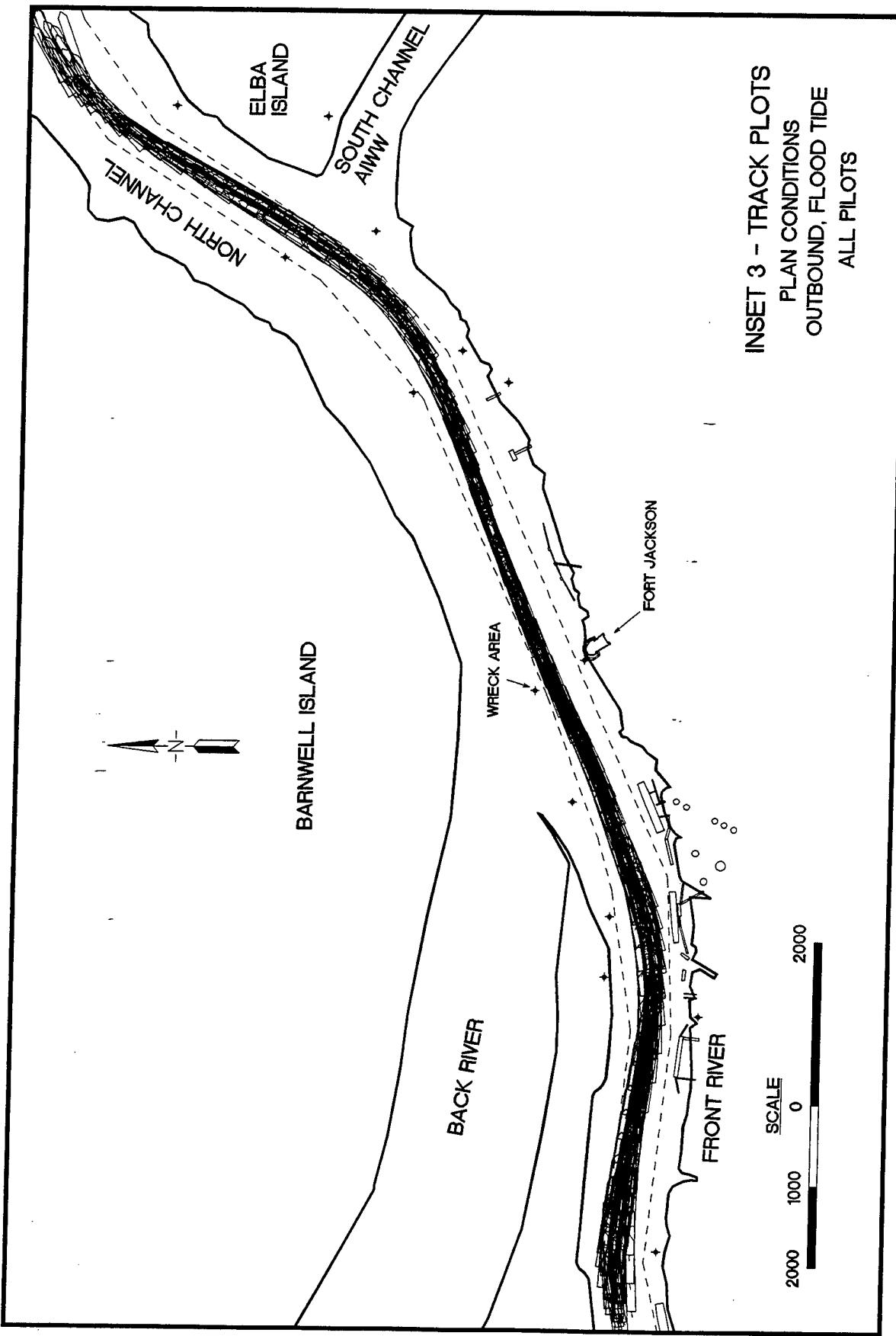


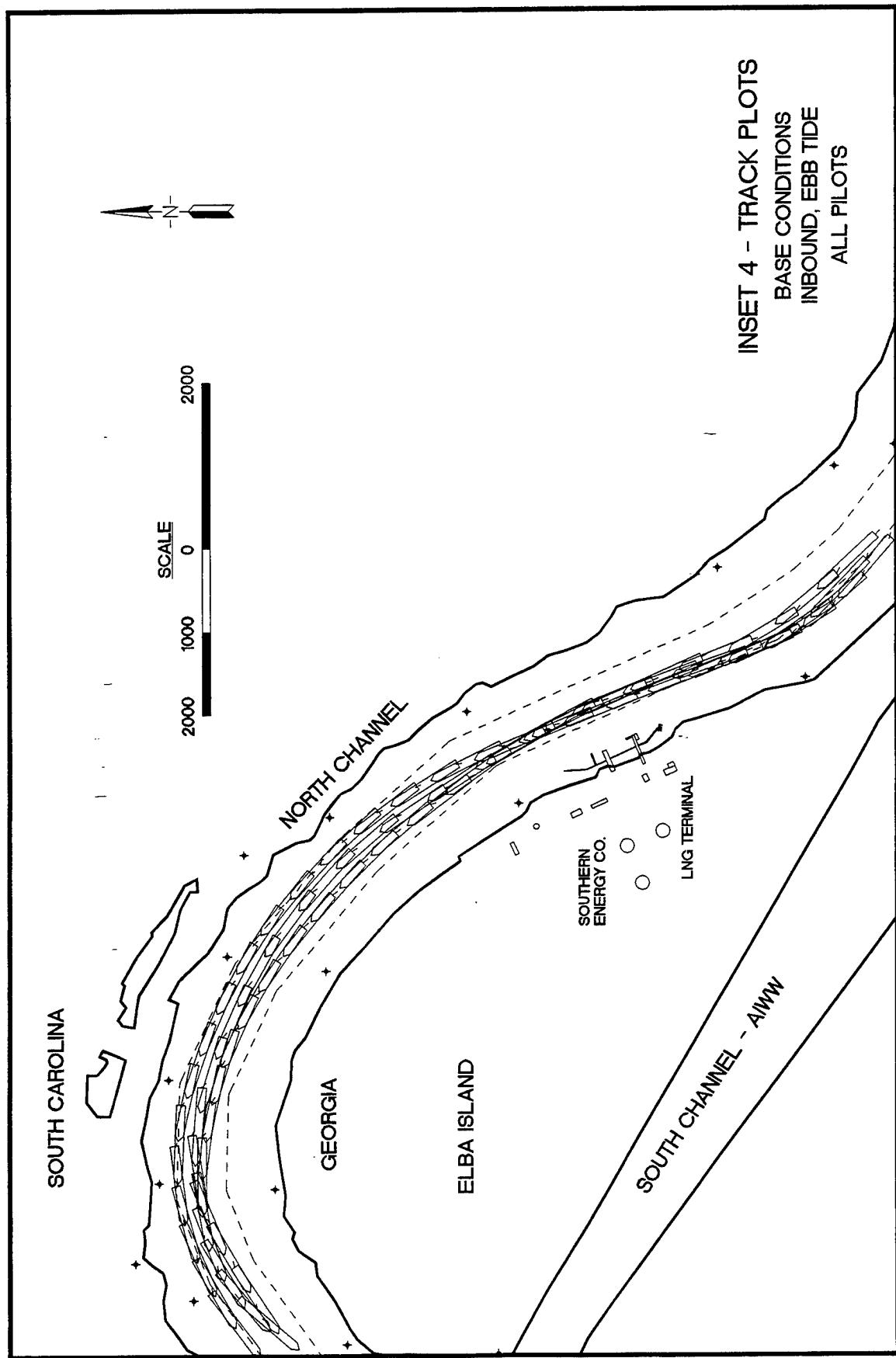
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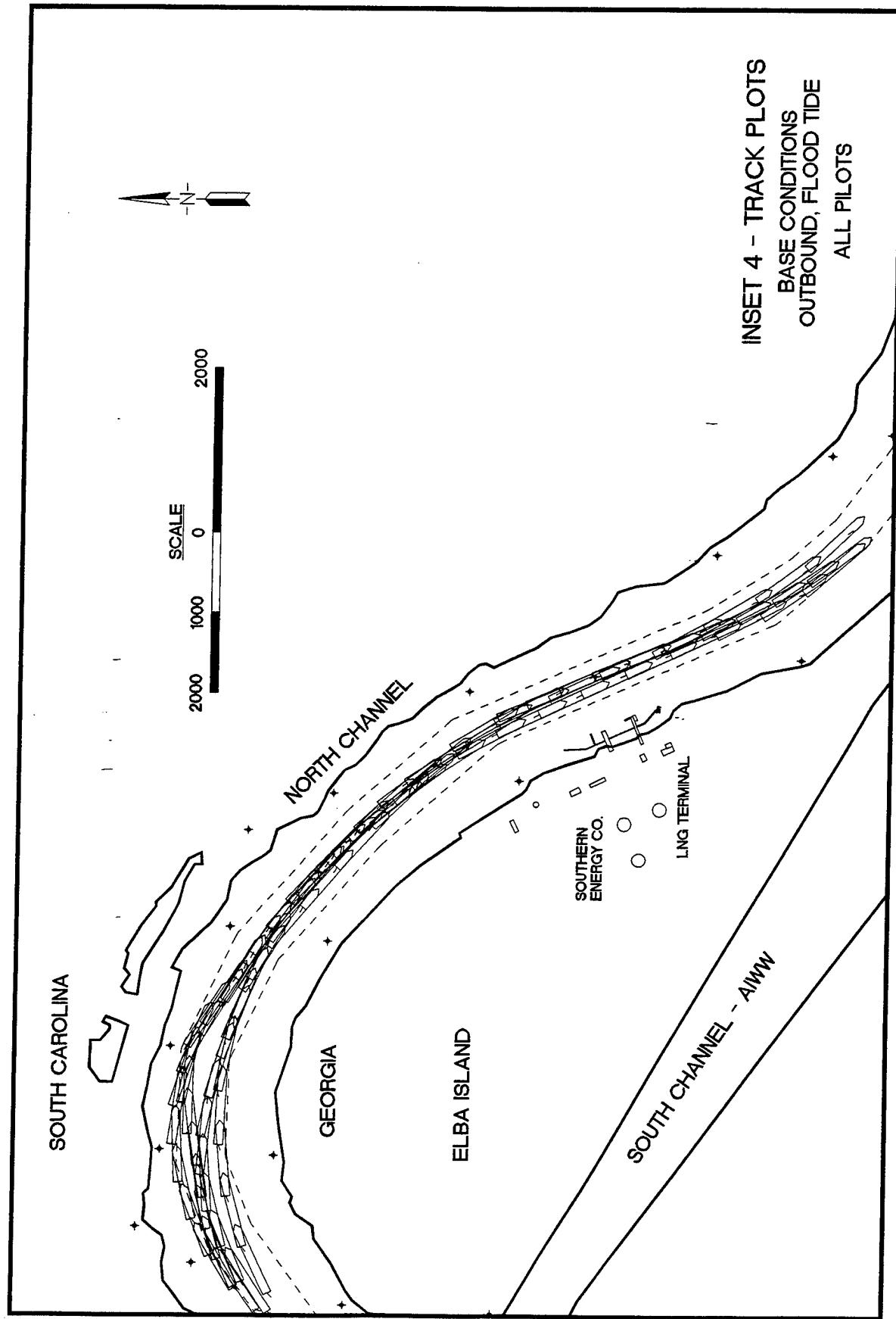


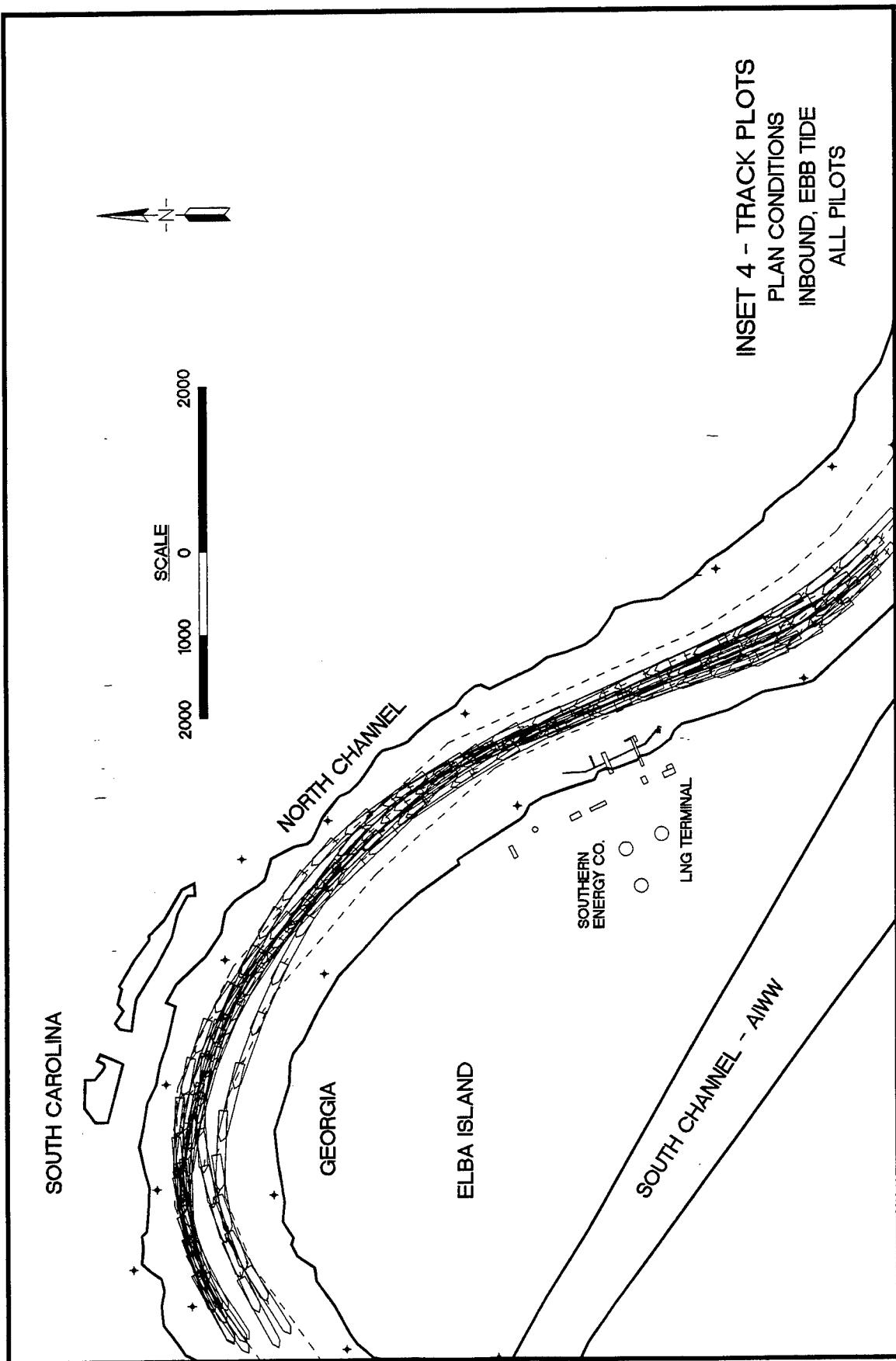












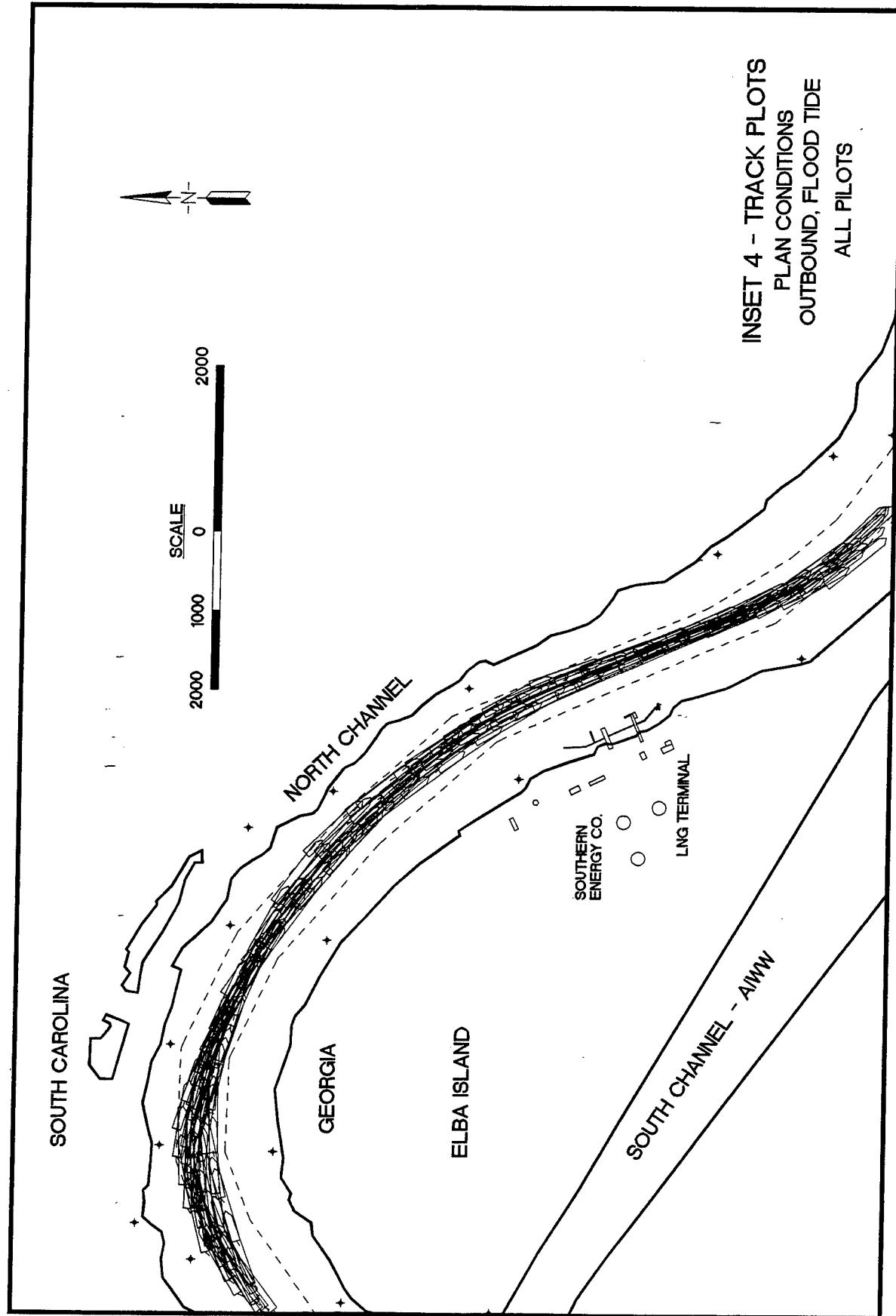
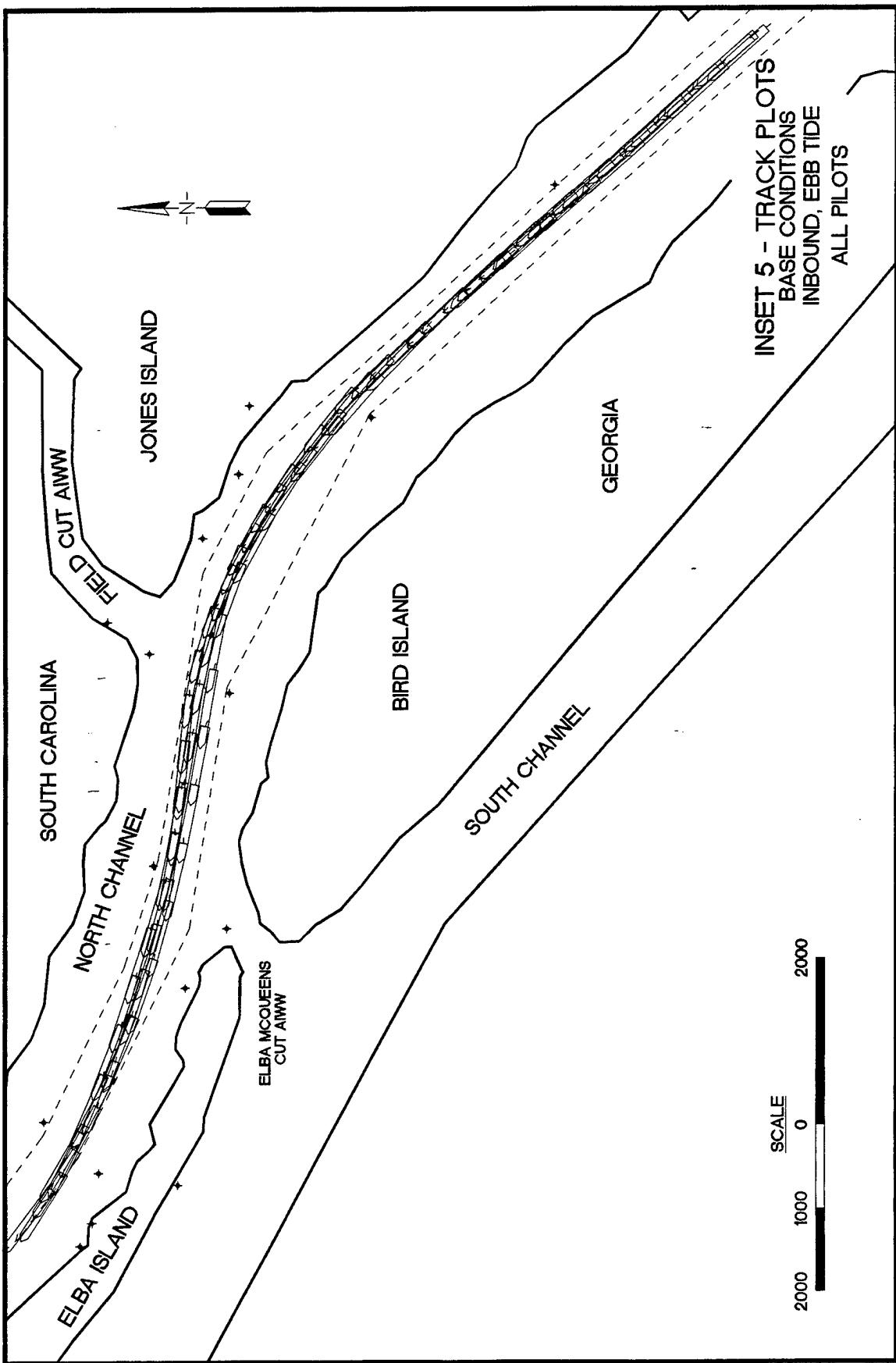
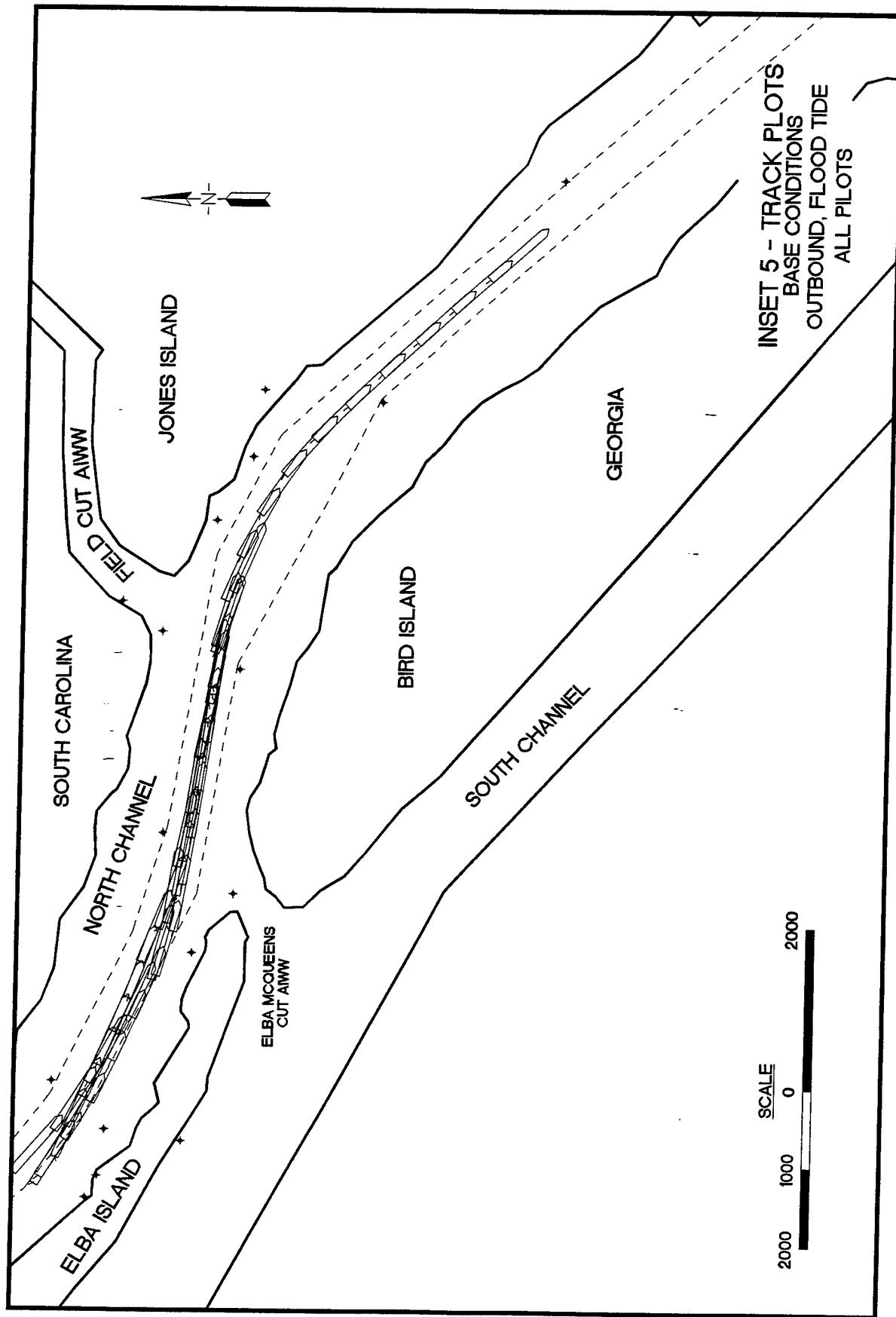
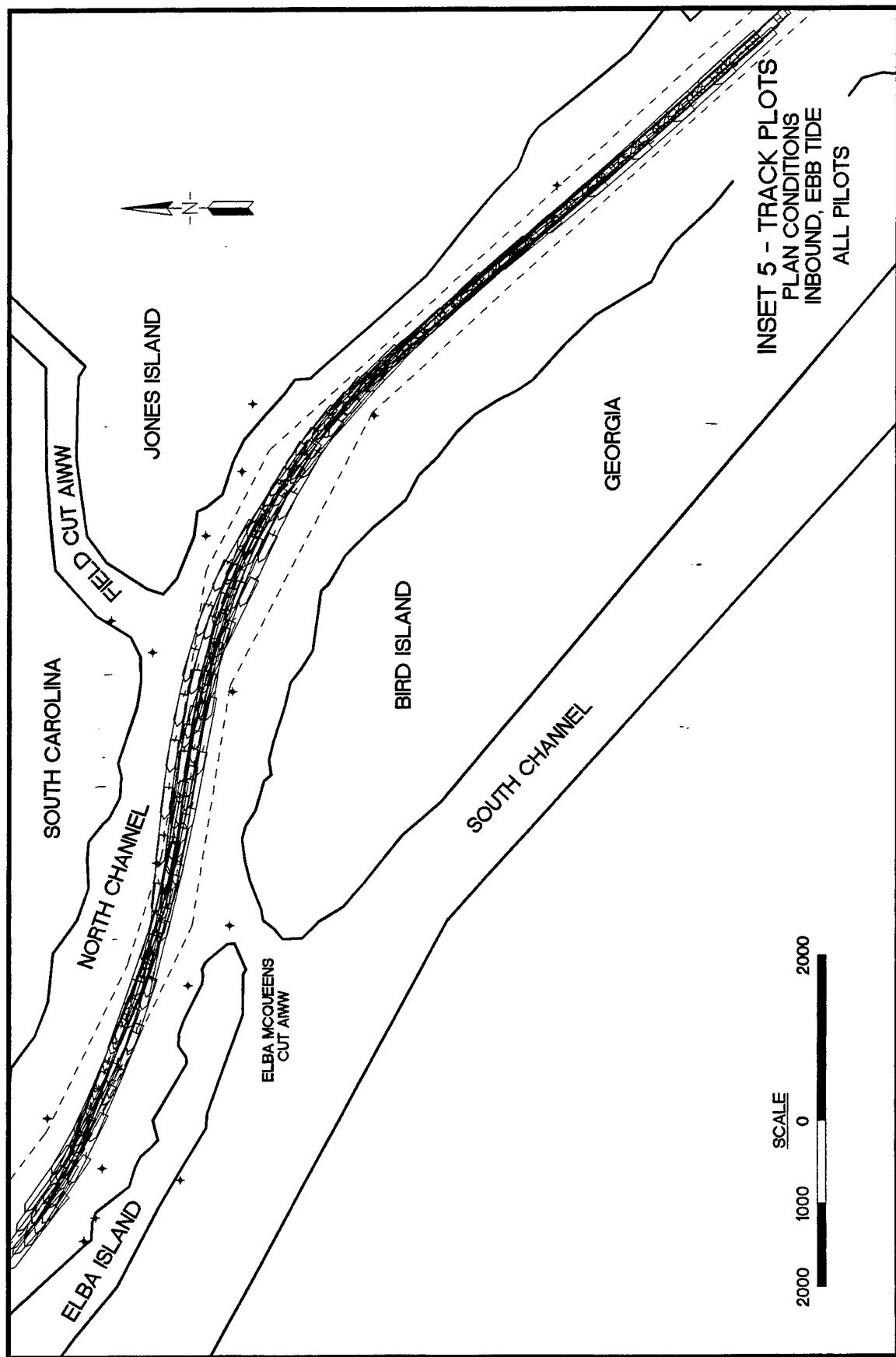


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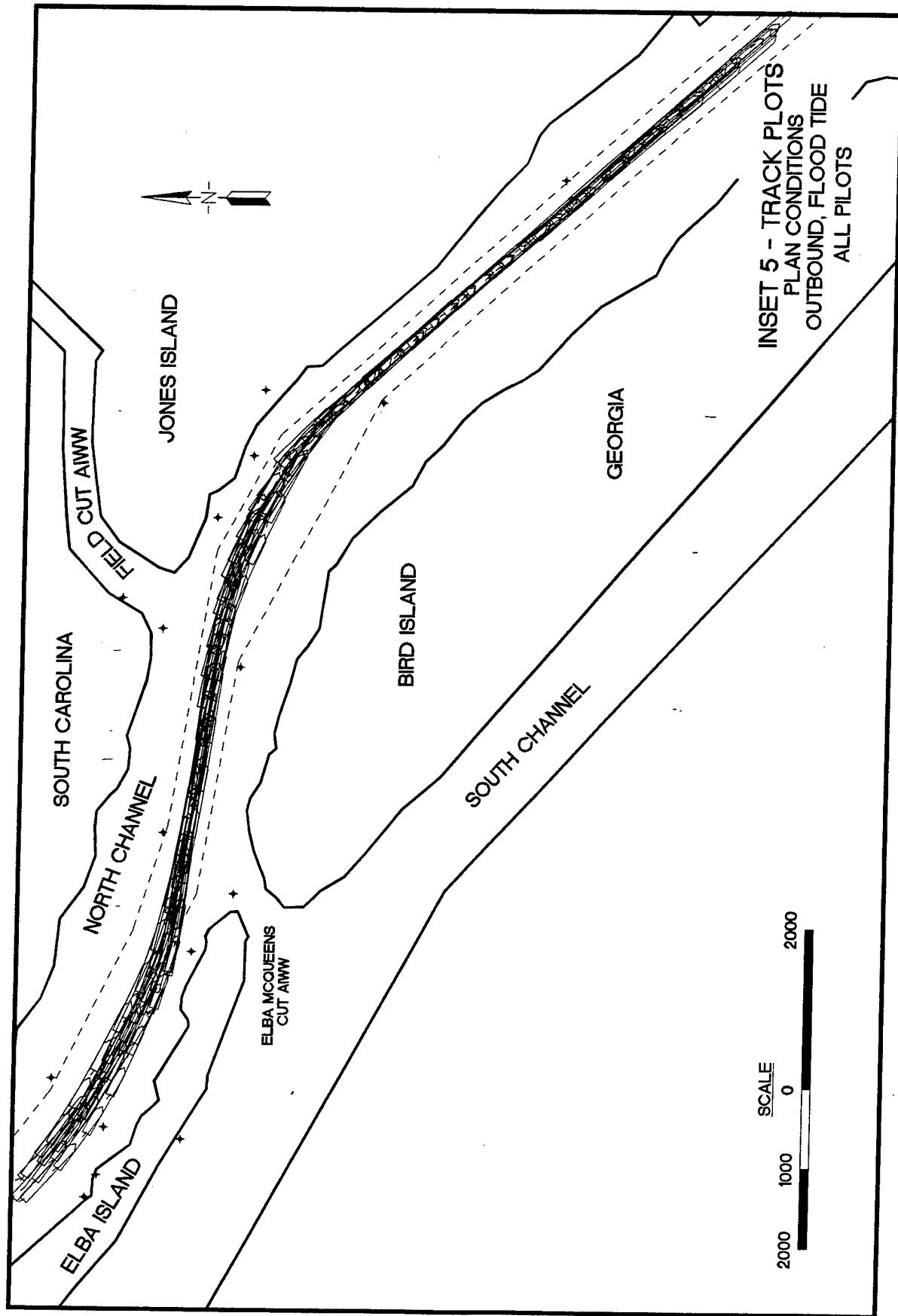
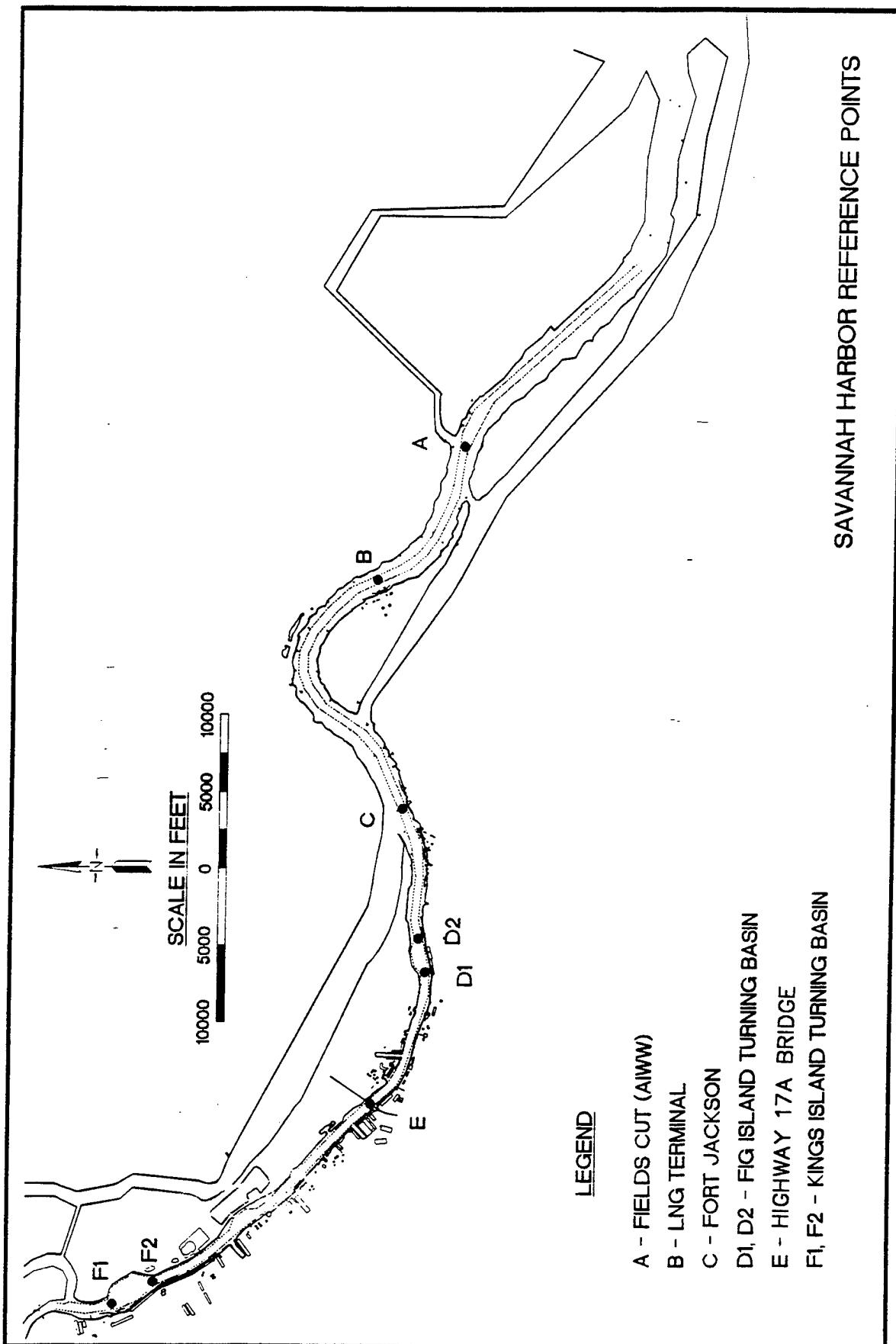
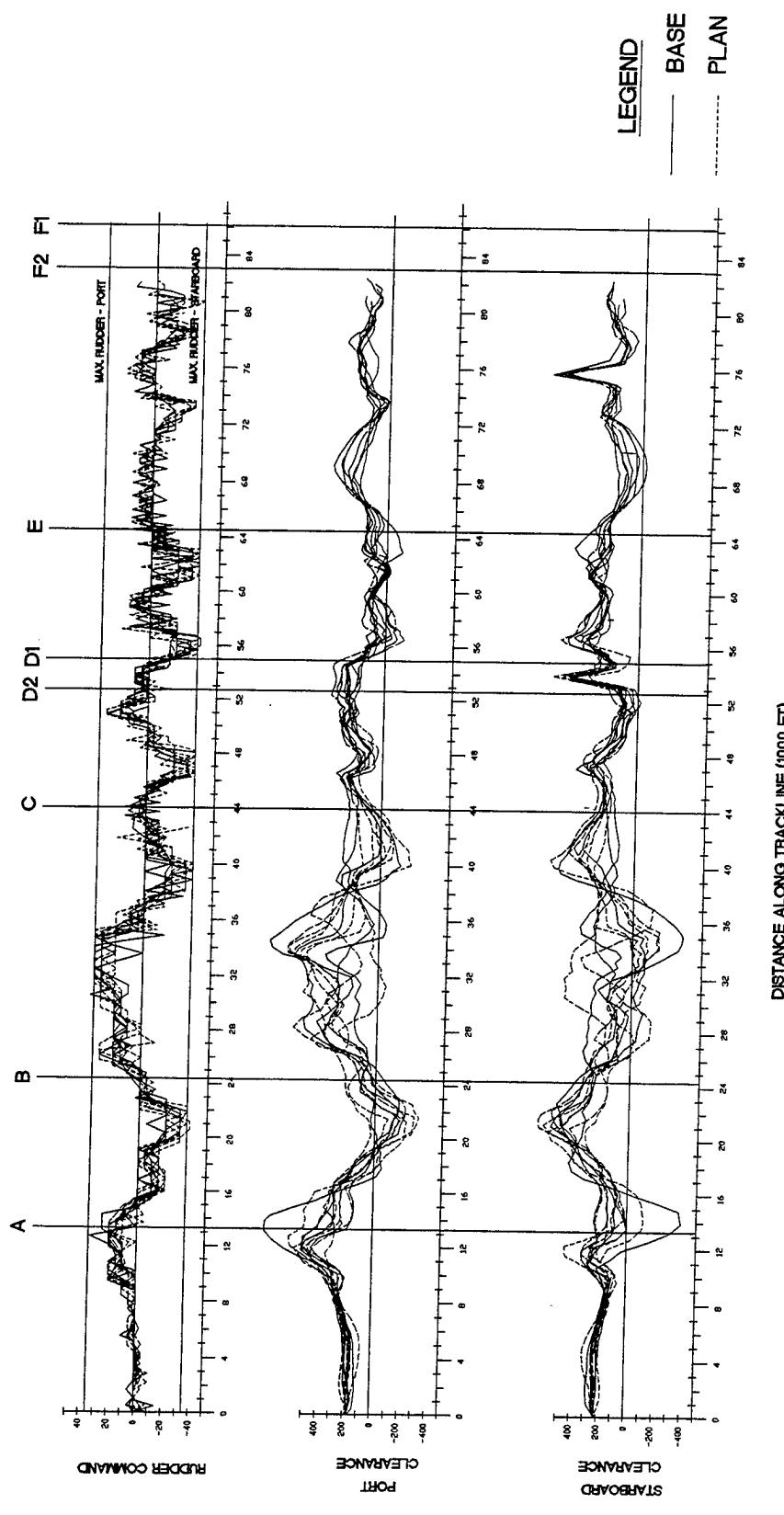


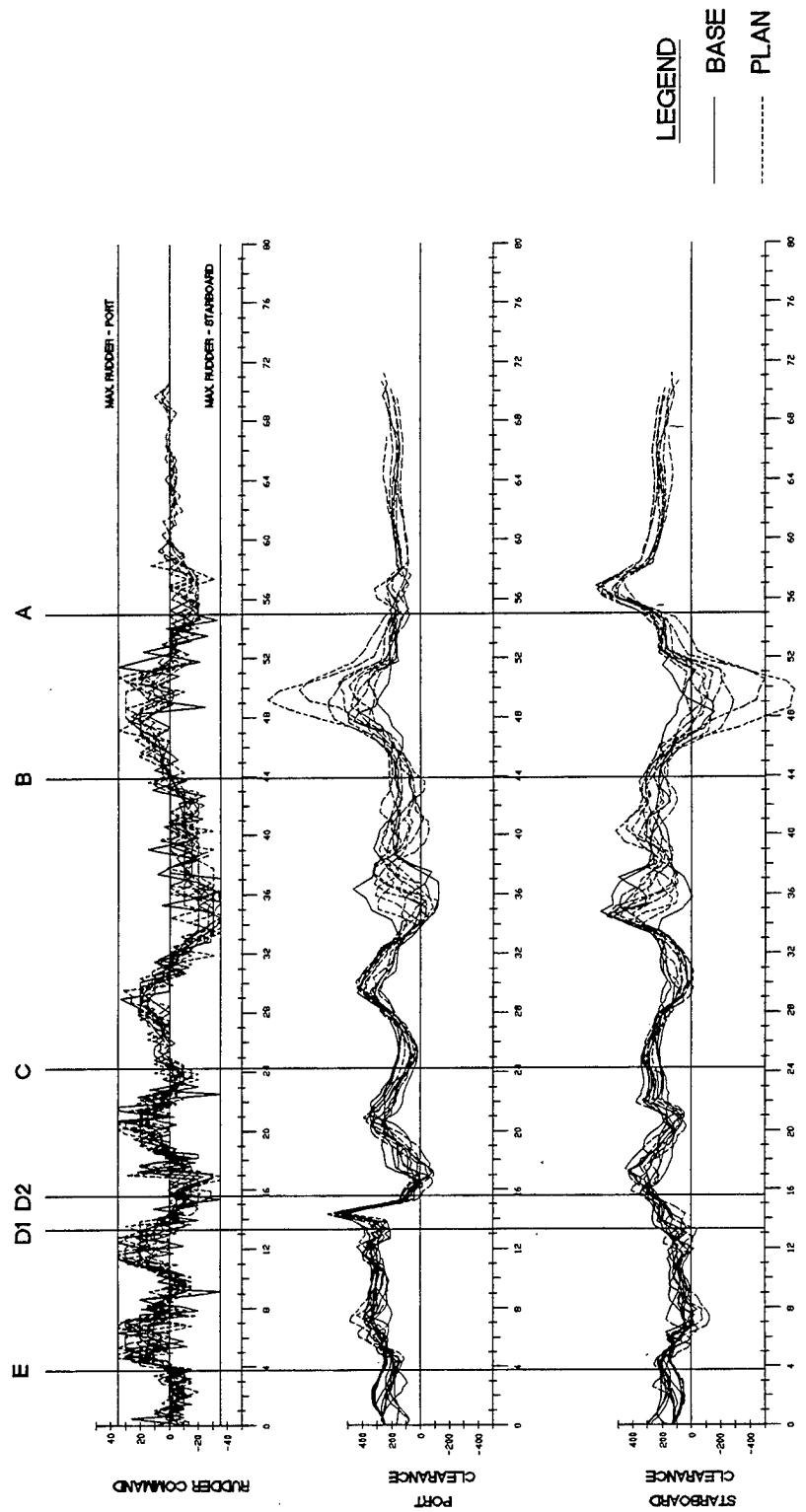
Plate 44



SAVANNAH HARBOR INBOUND RUNS



SAVANNAH HARBOR OUTBOUND RUNS



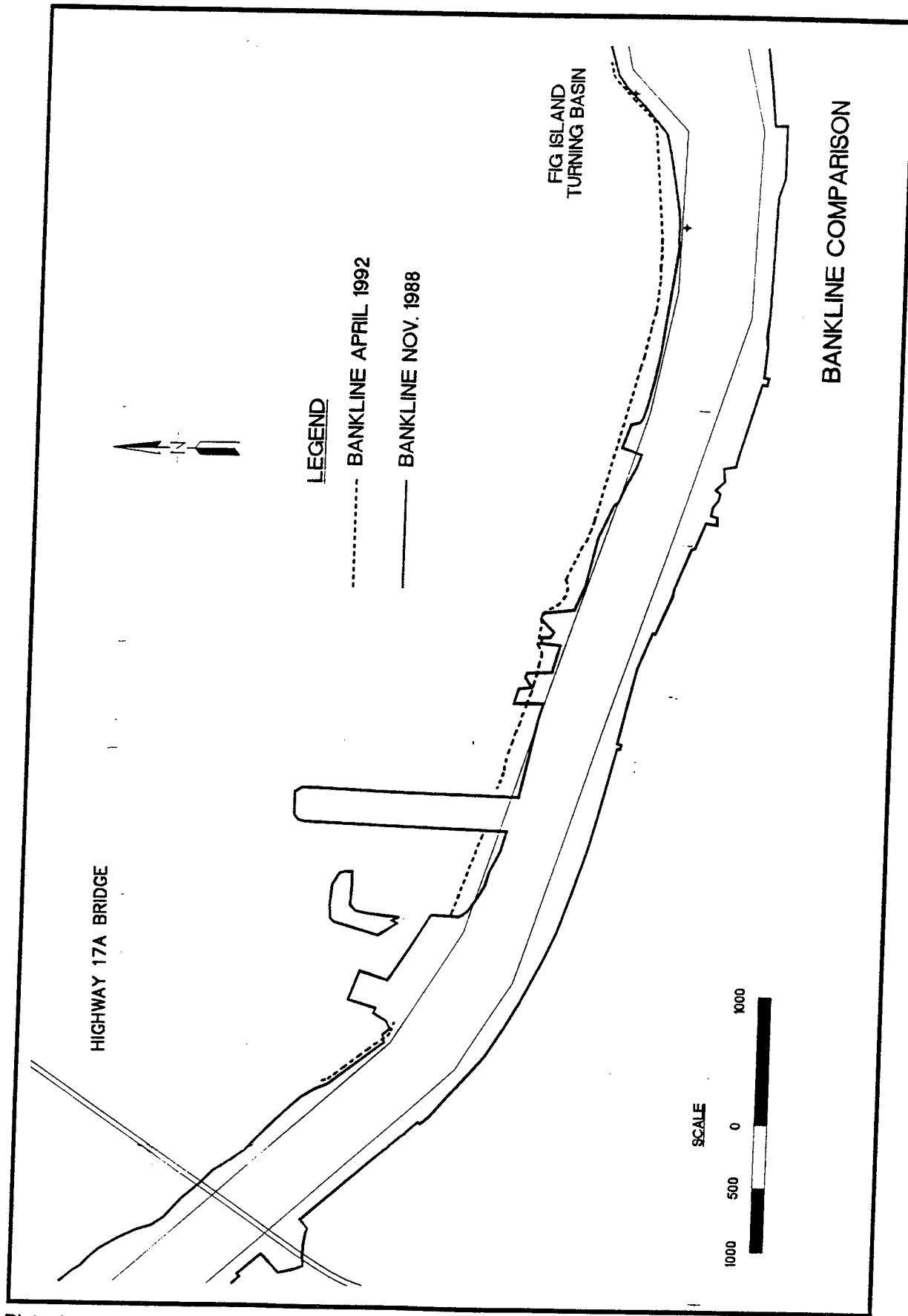
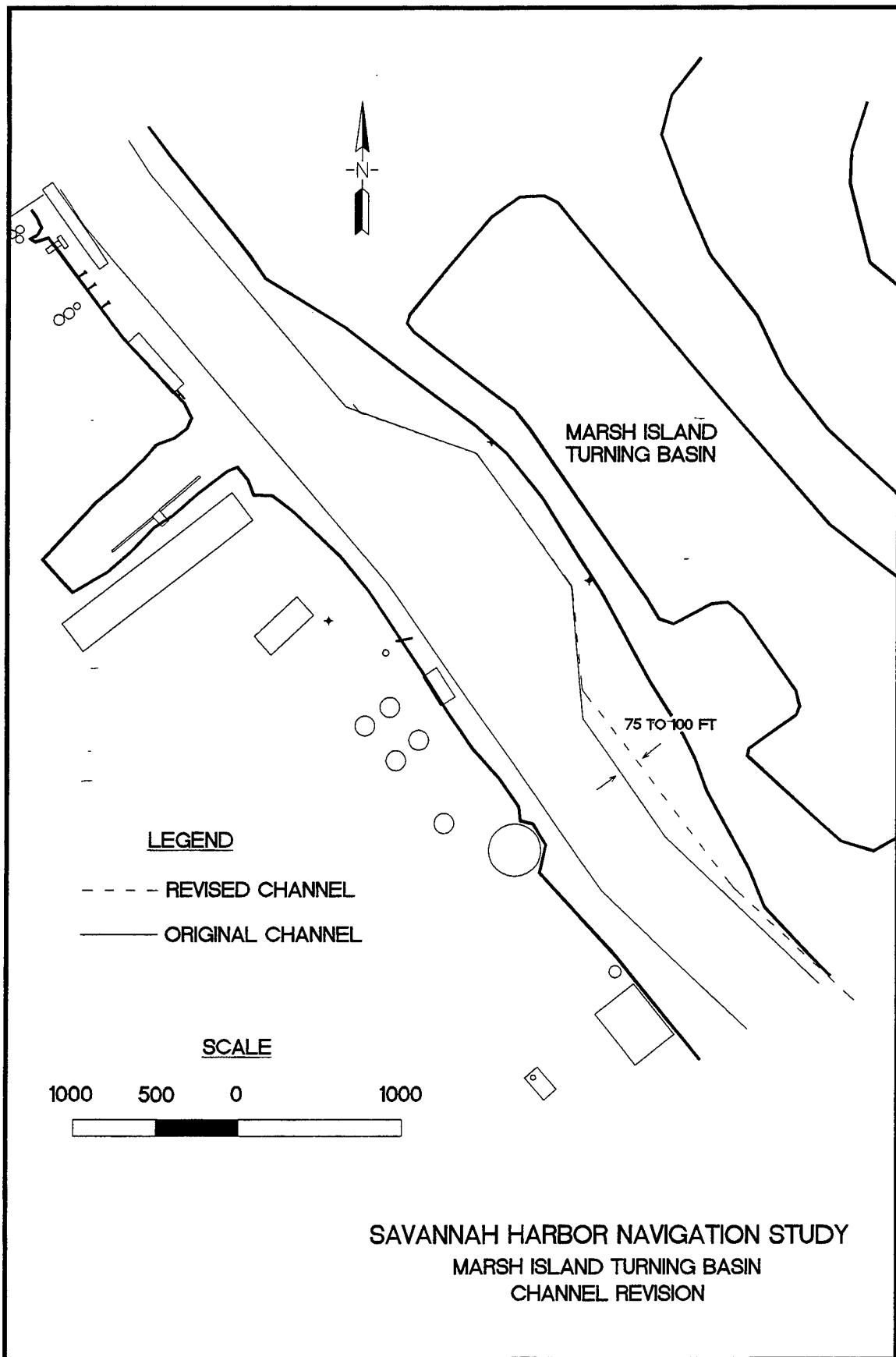
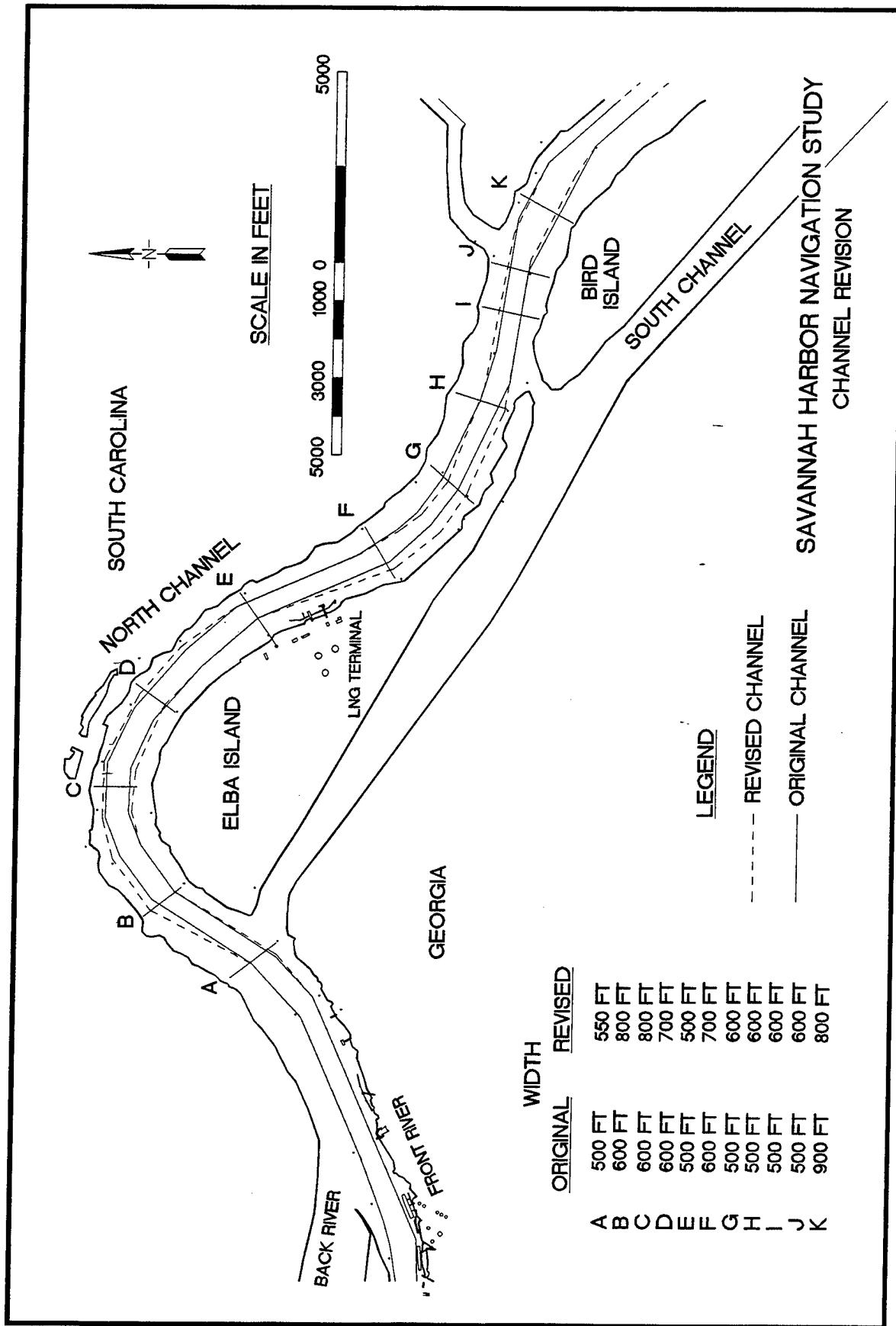
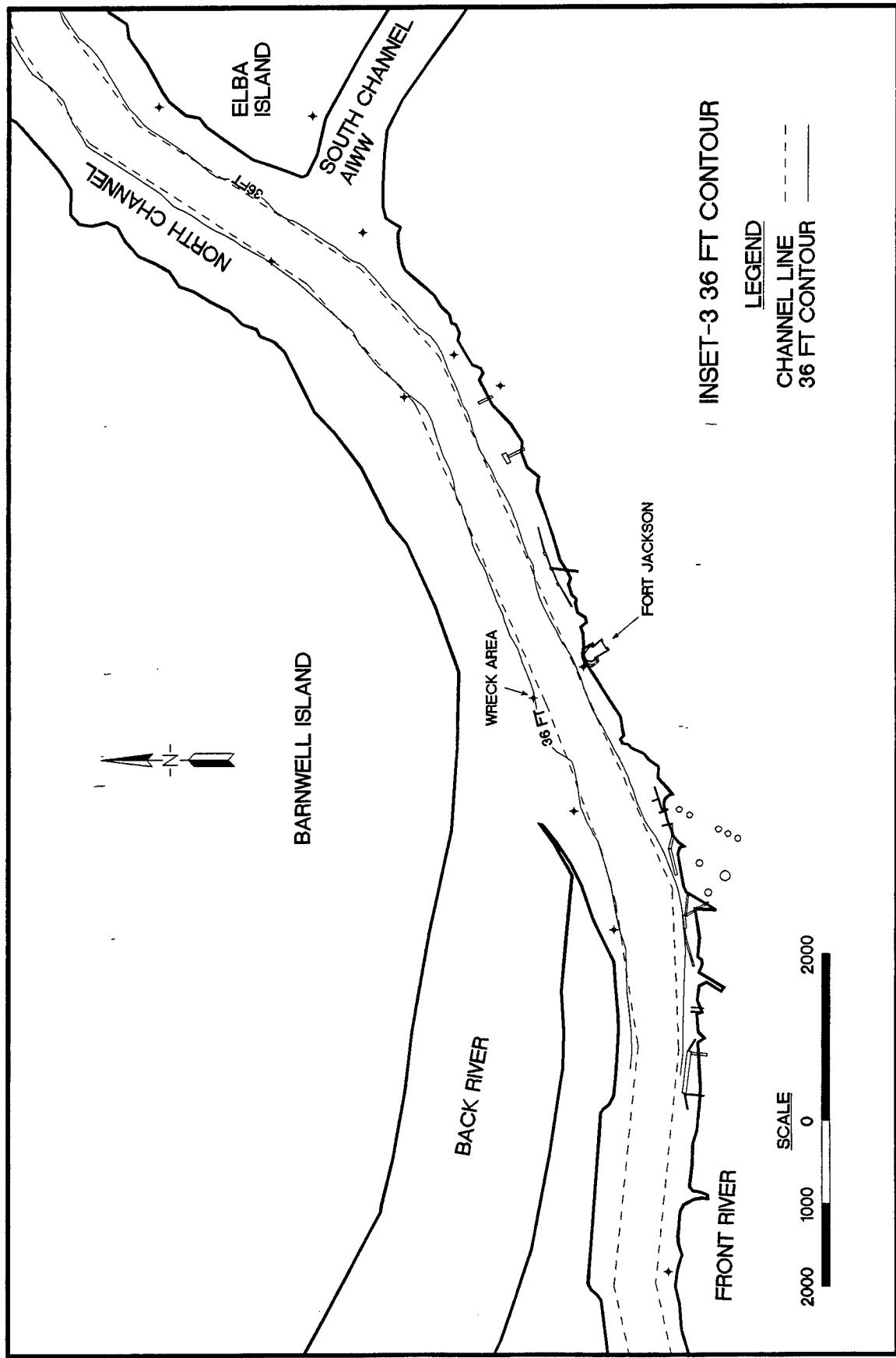


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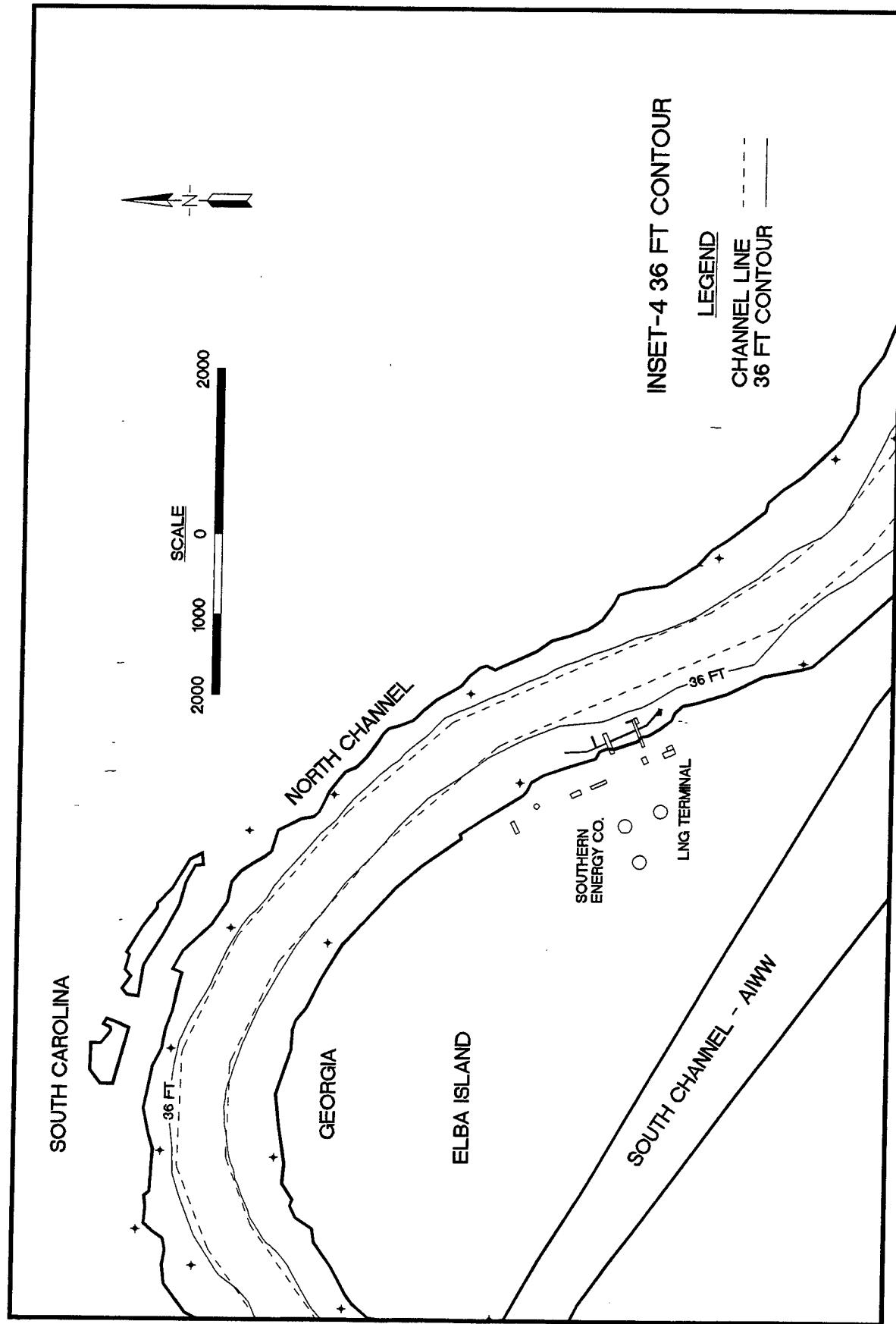
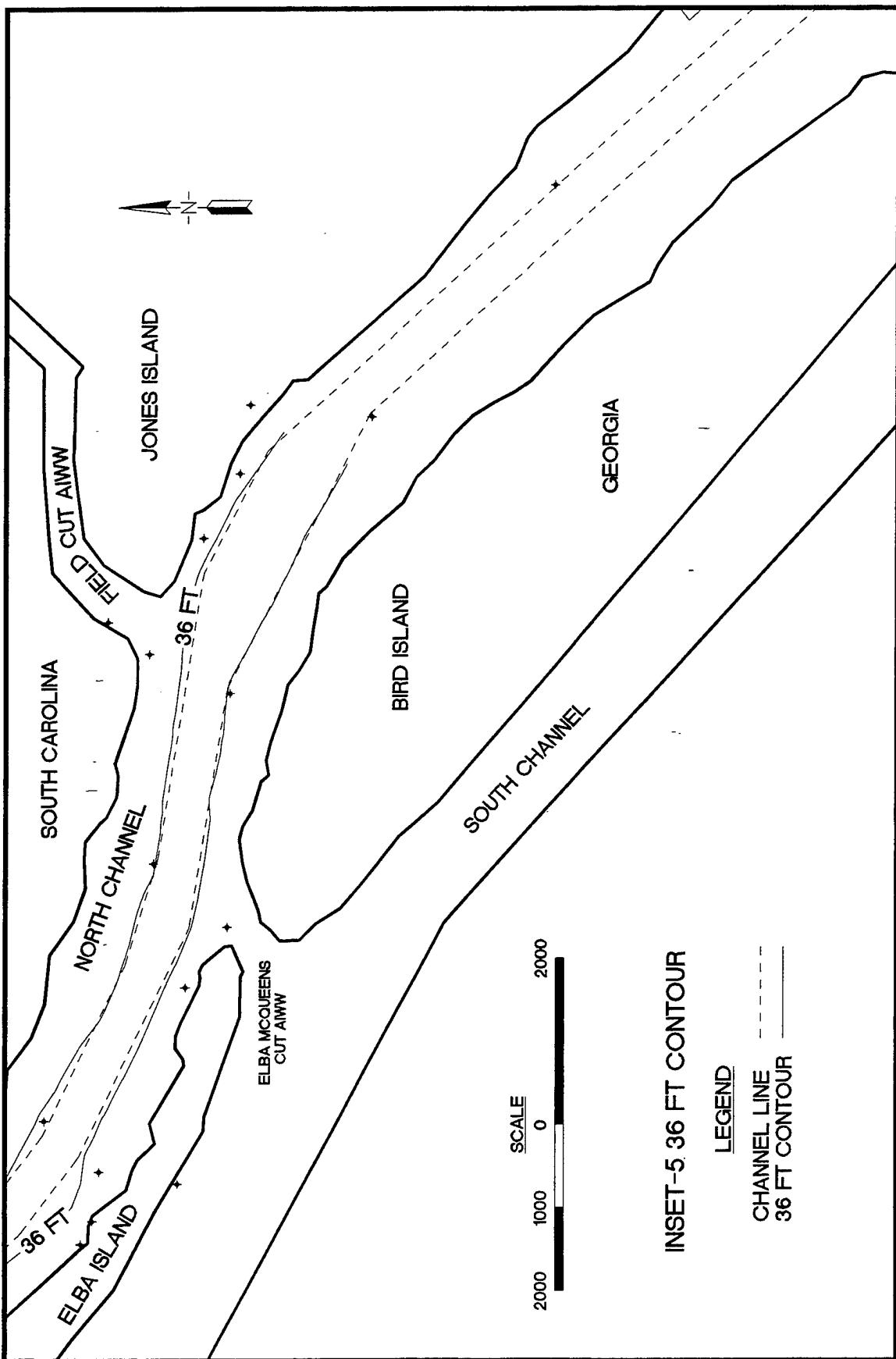


Plate 52



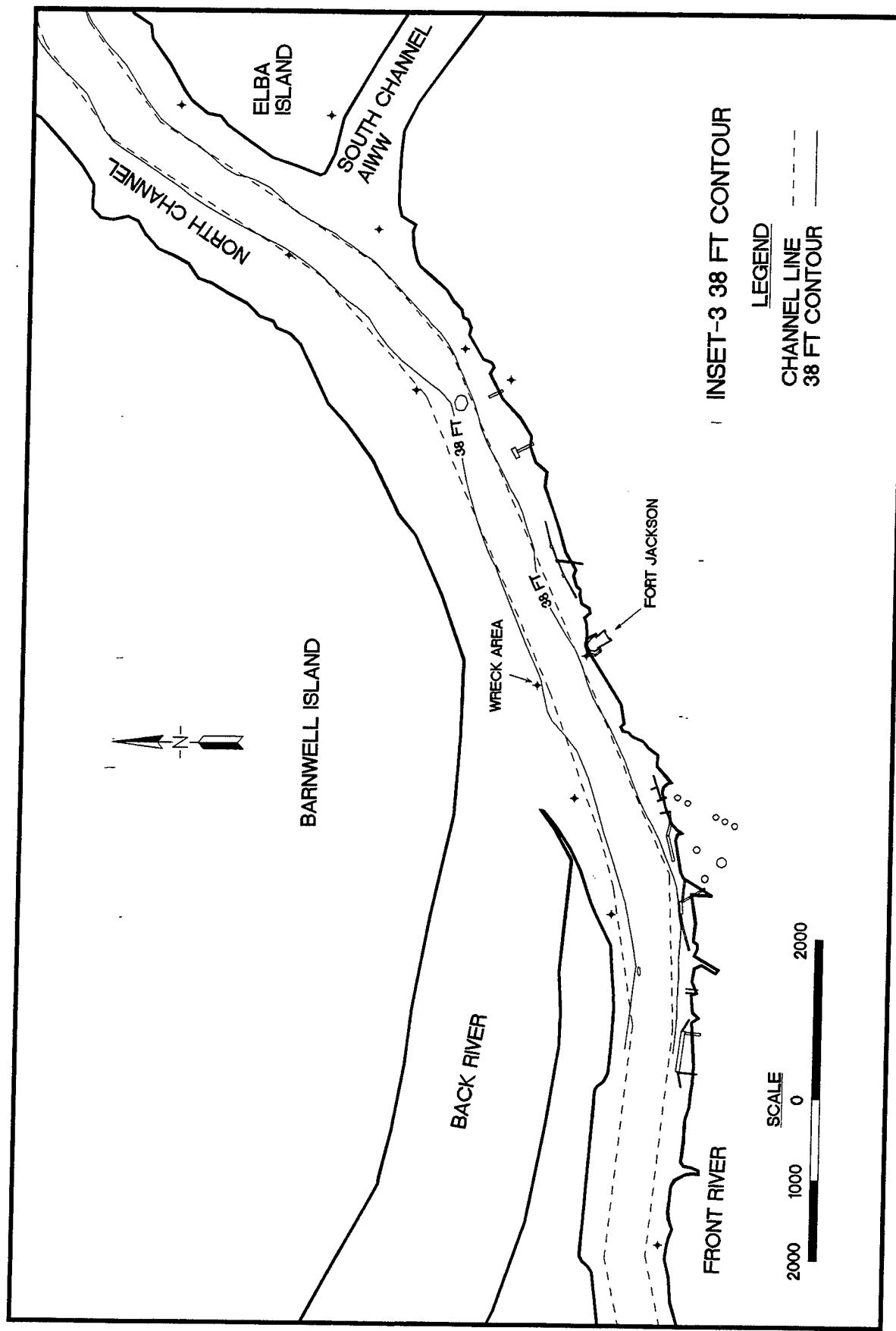
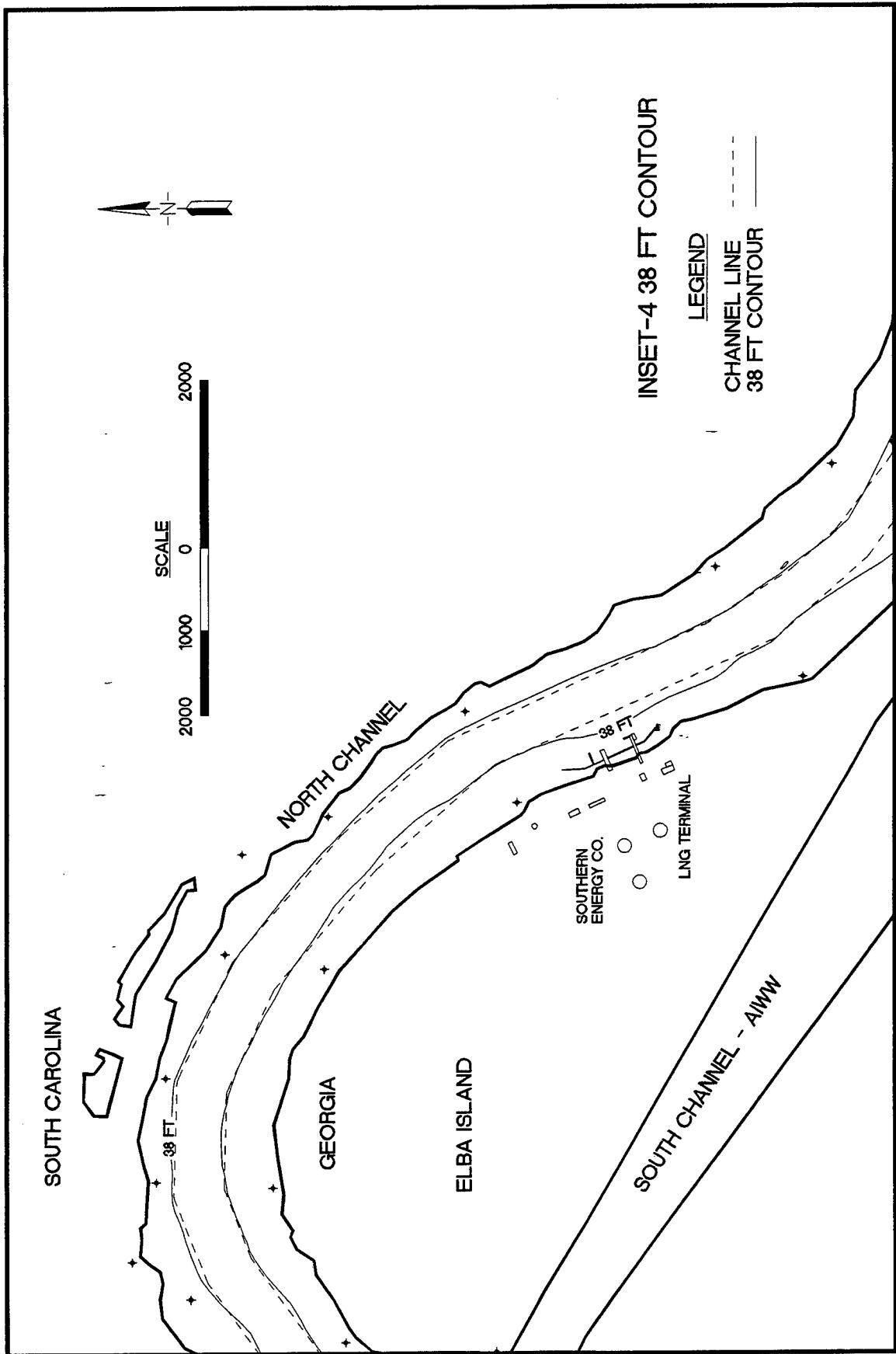
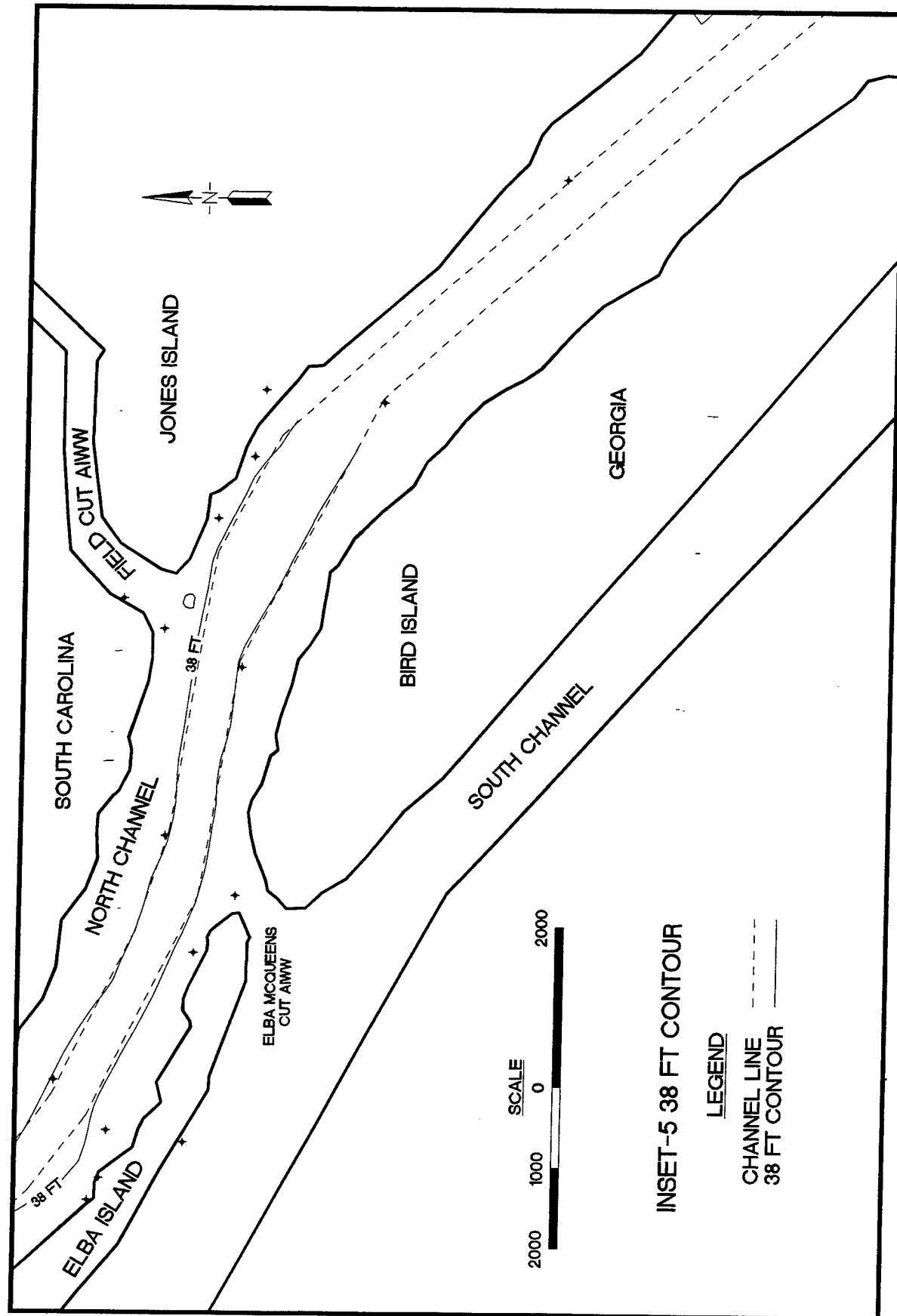
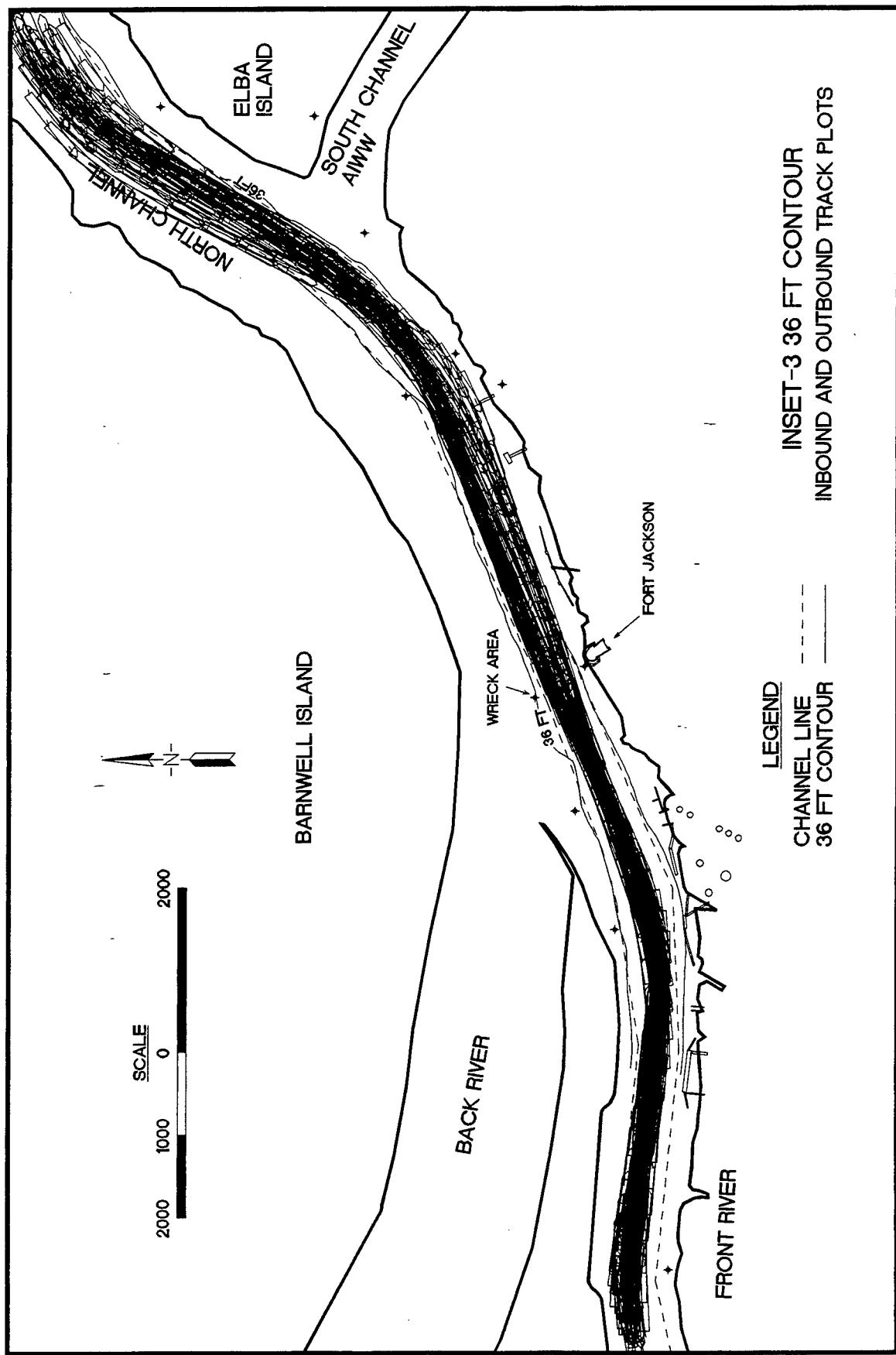


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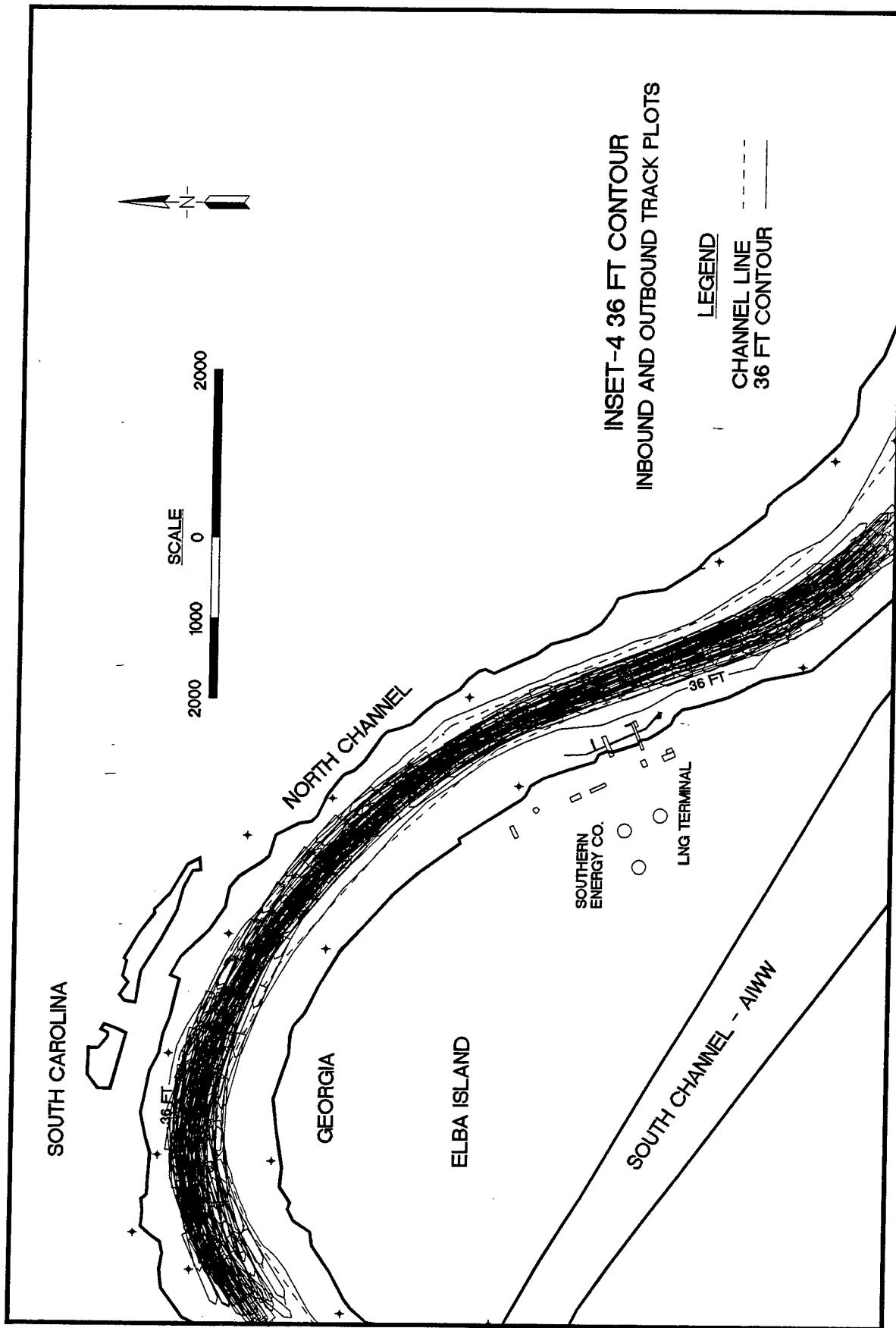
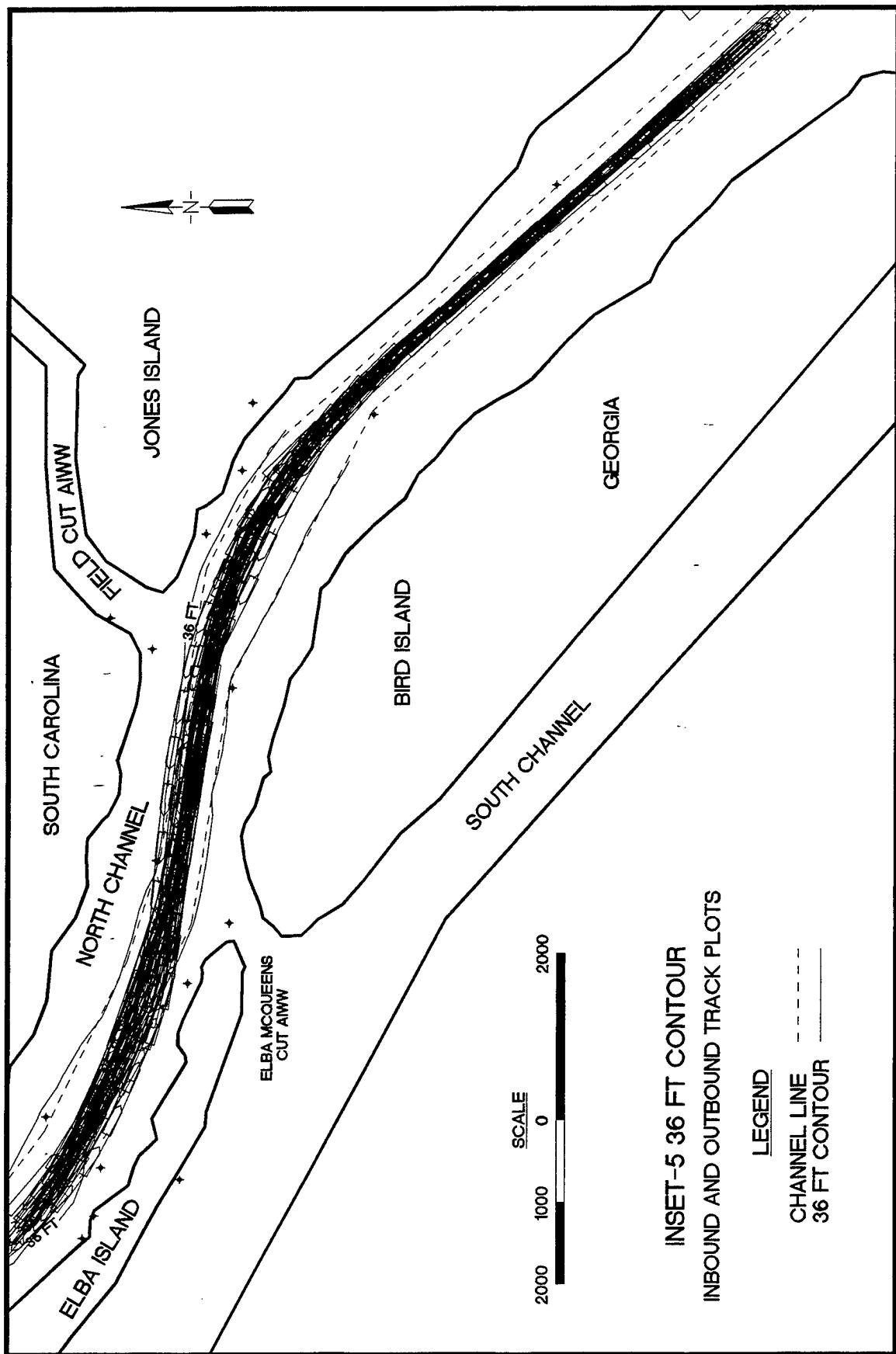
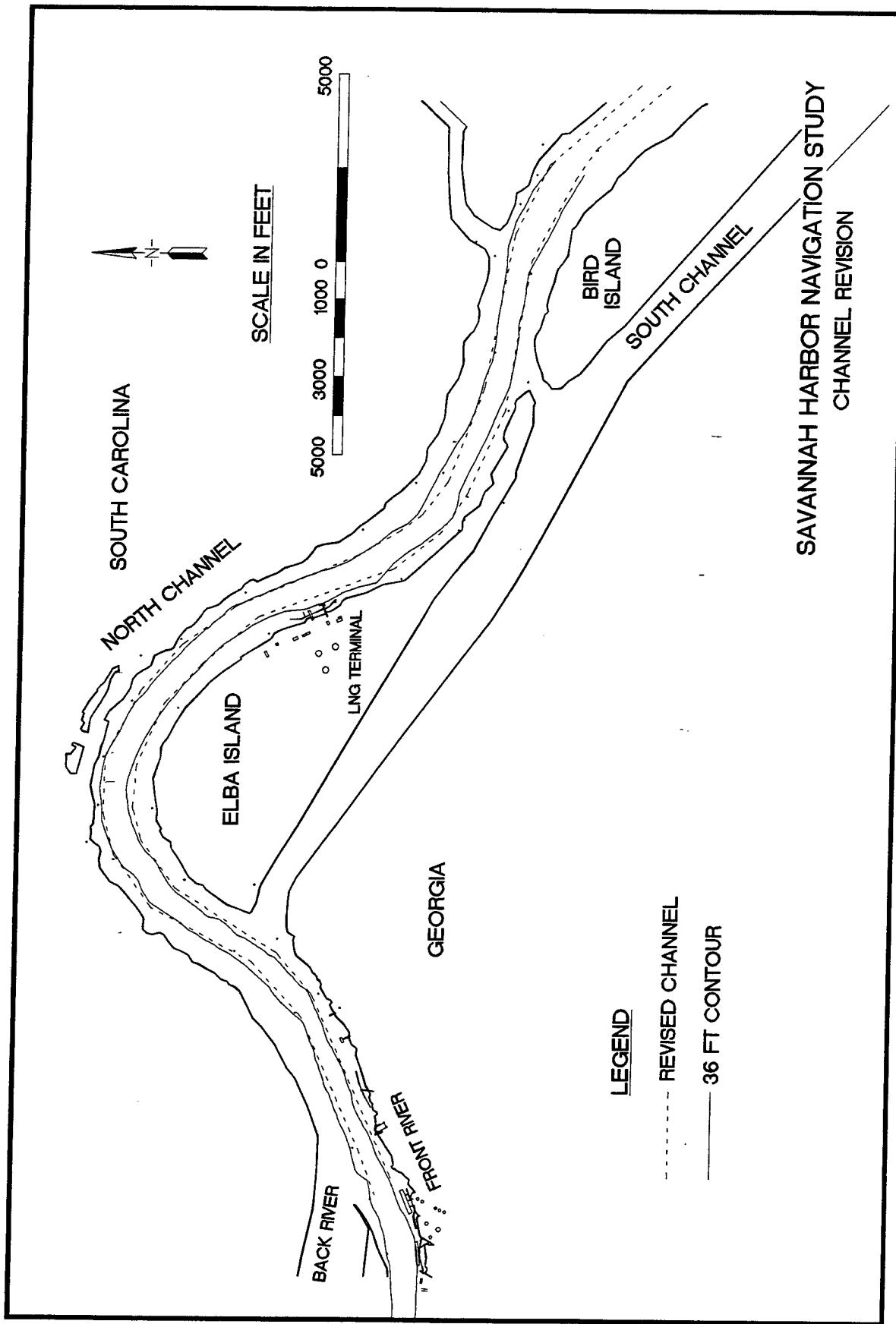
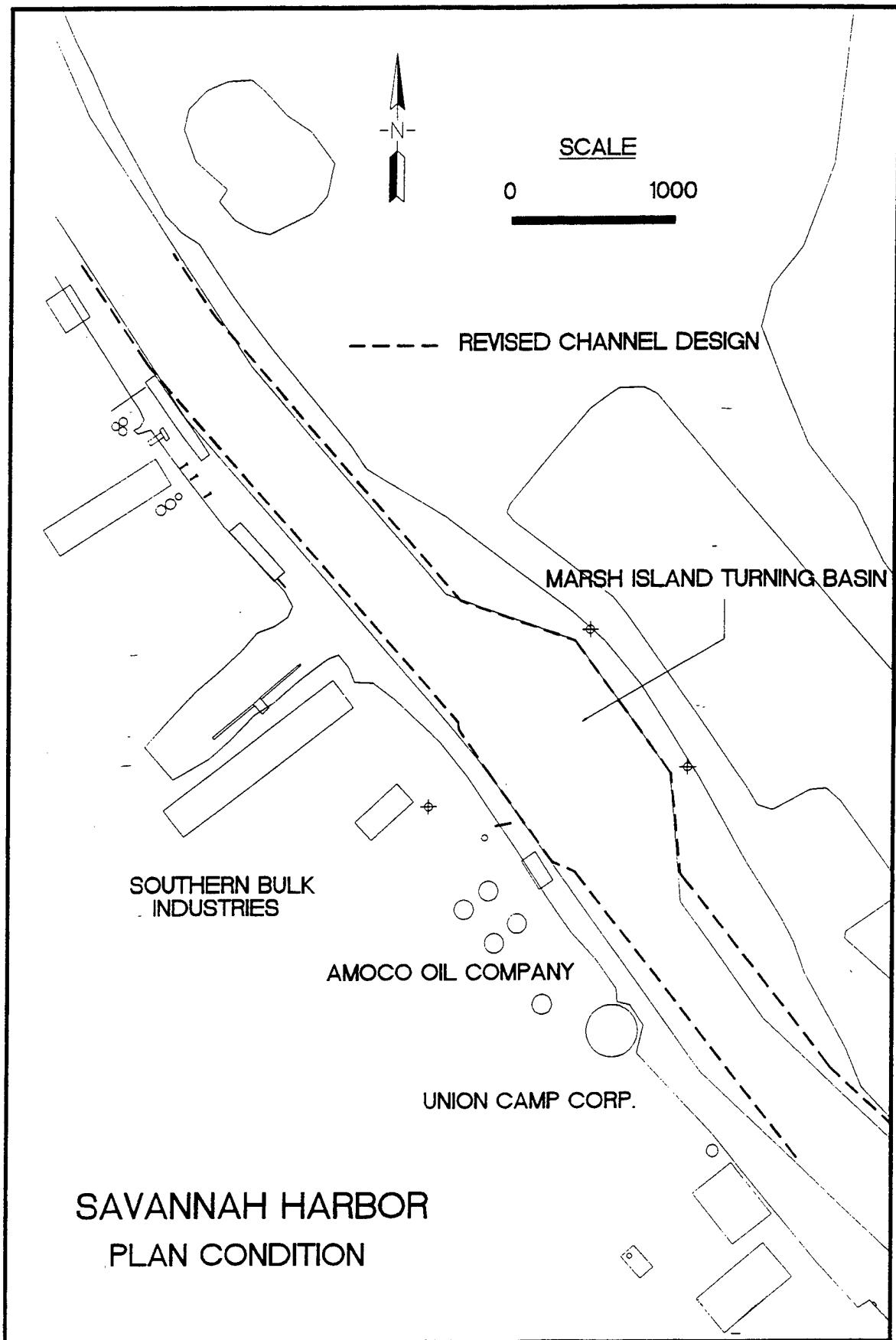
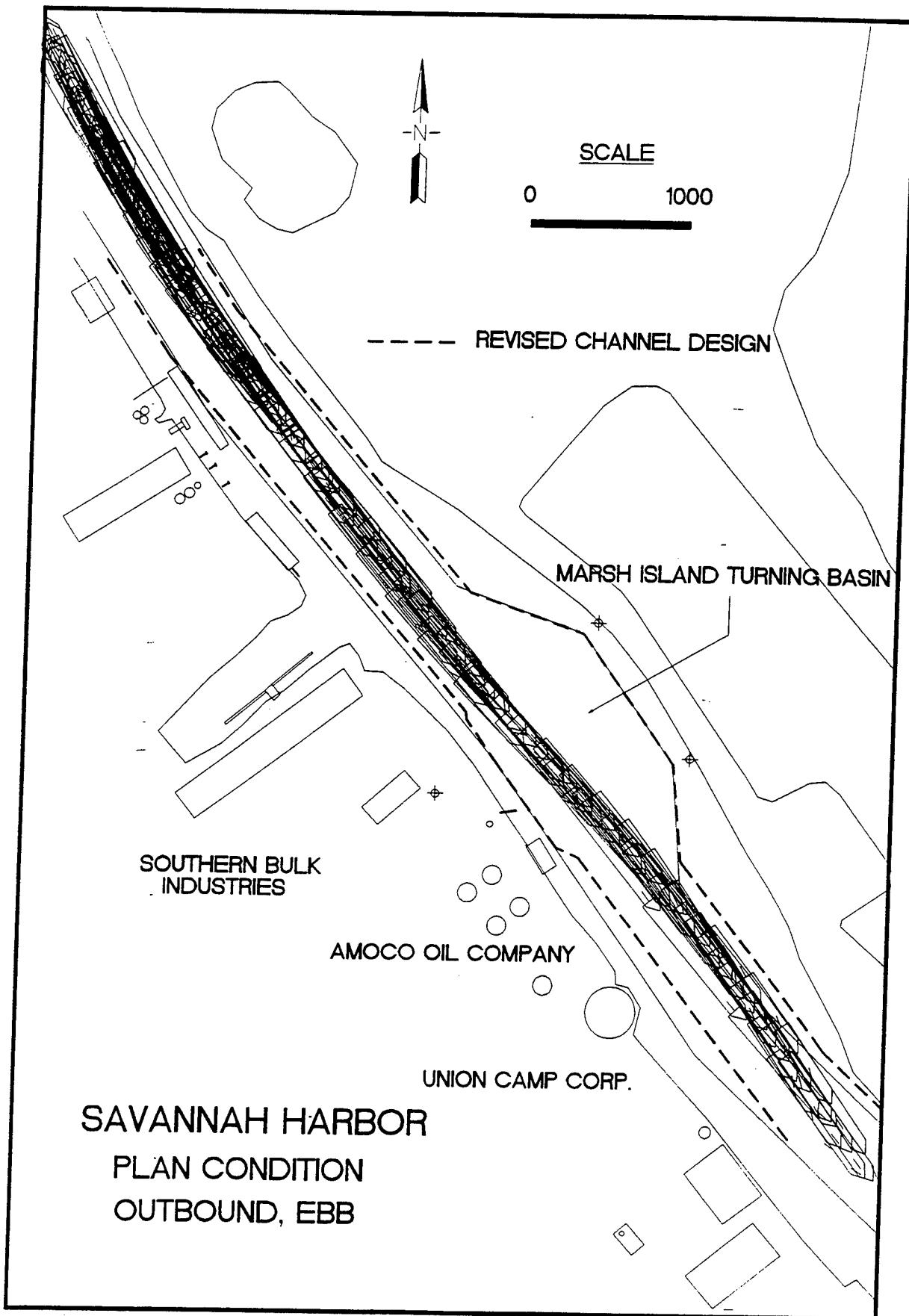


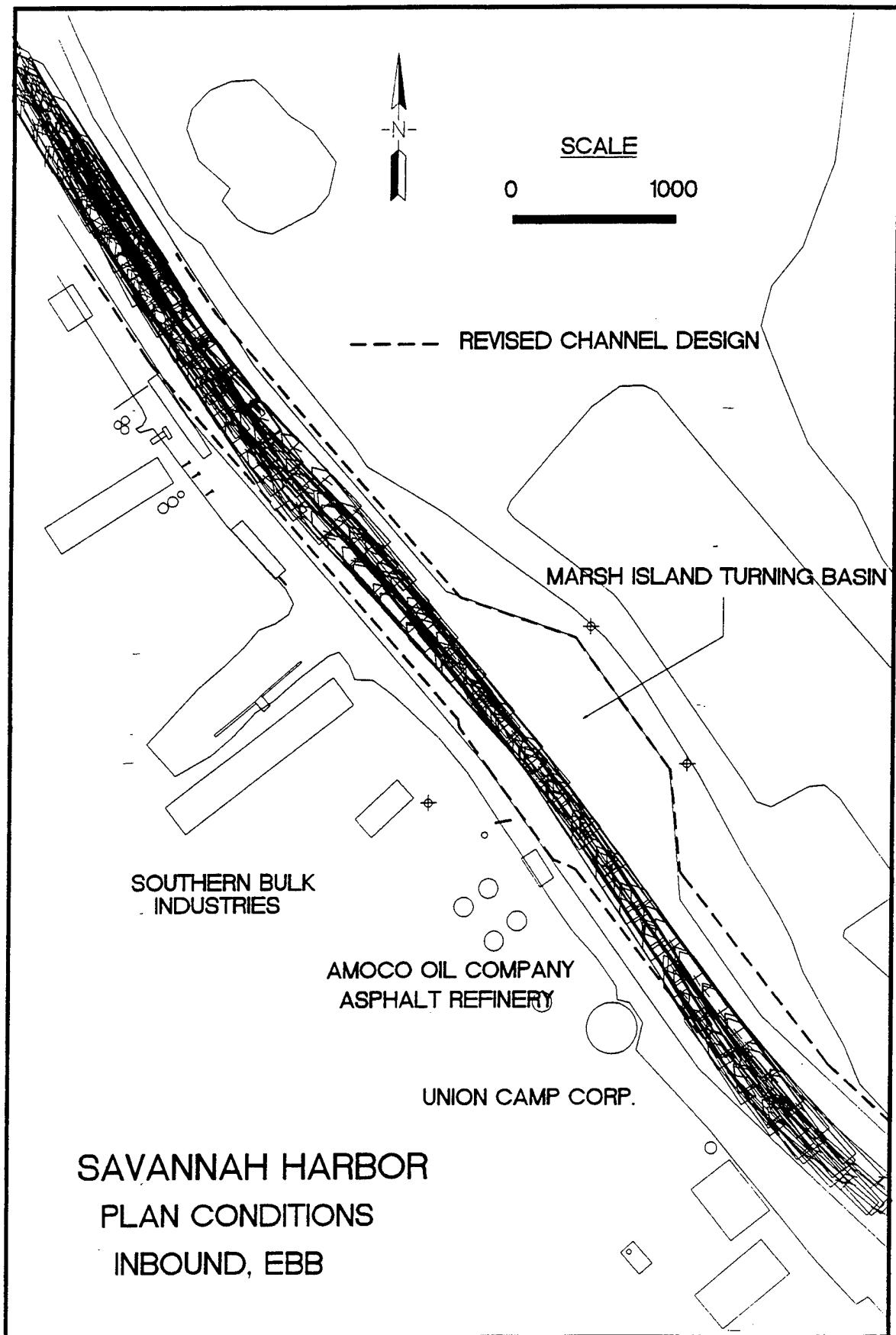
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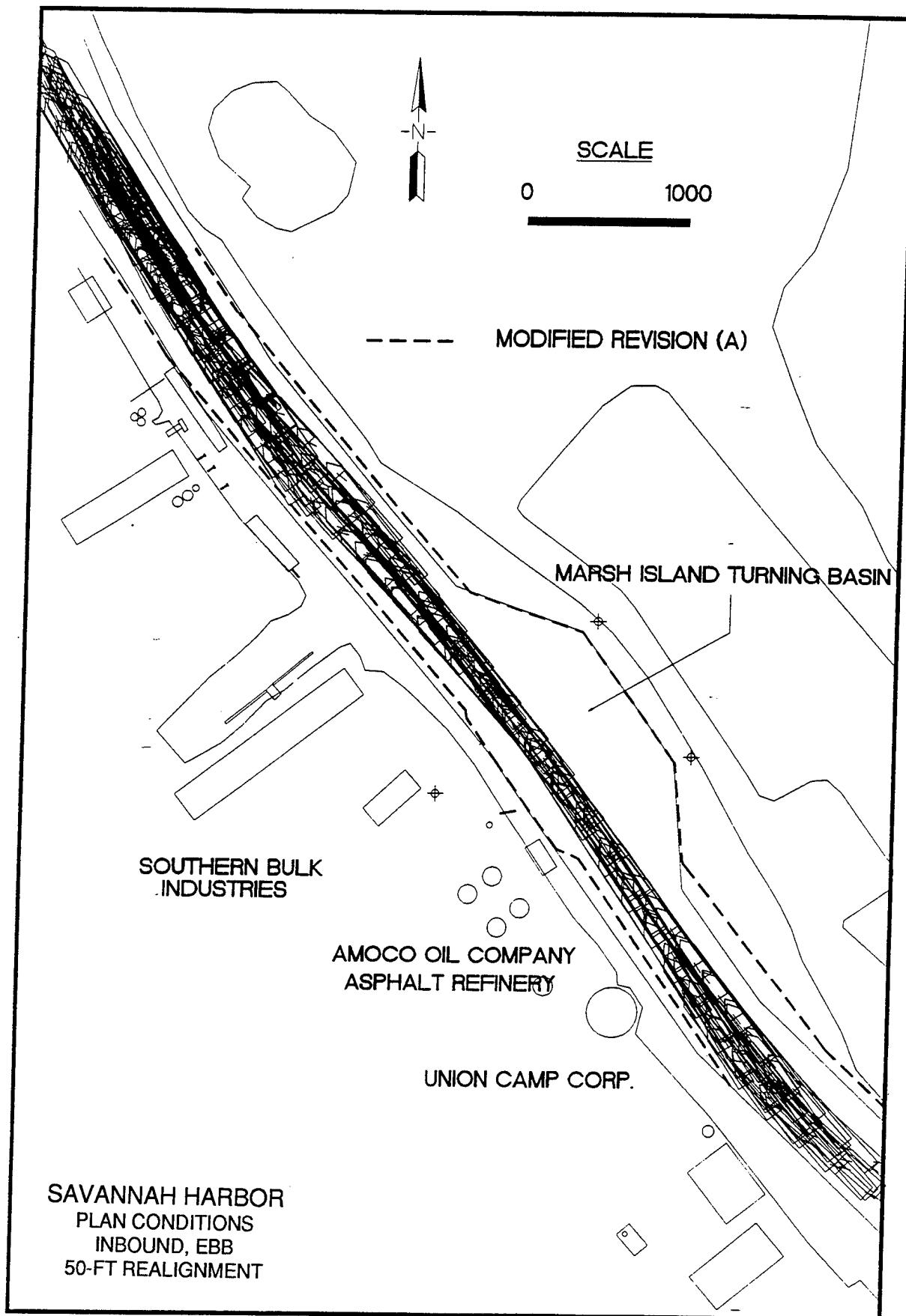


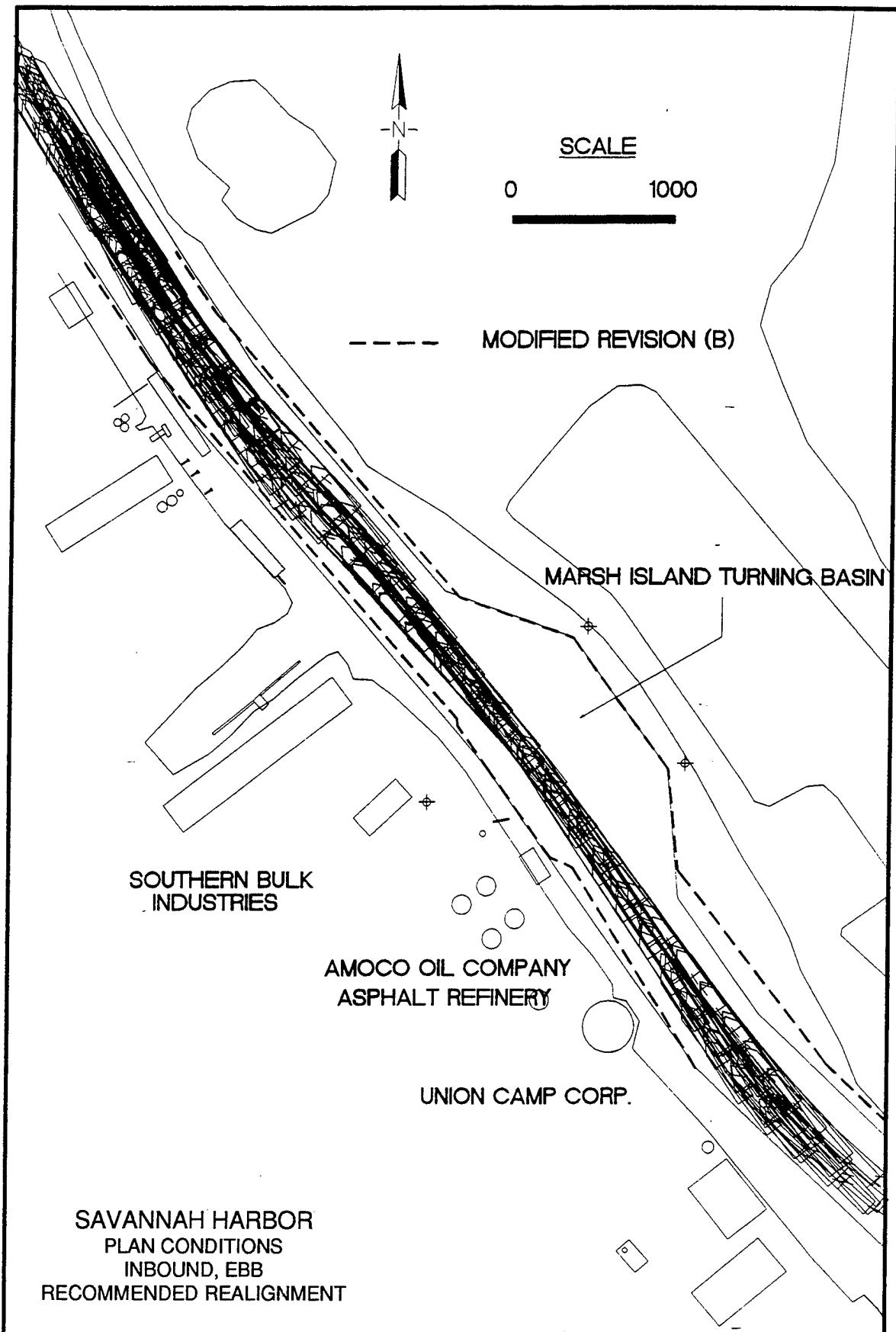


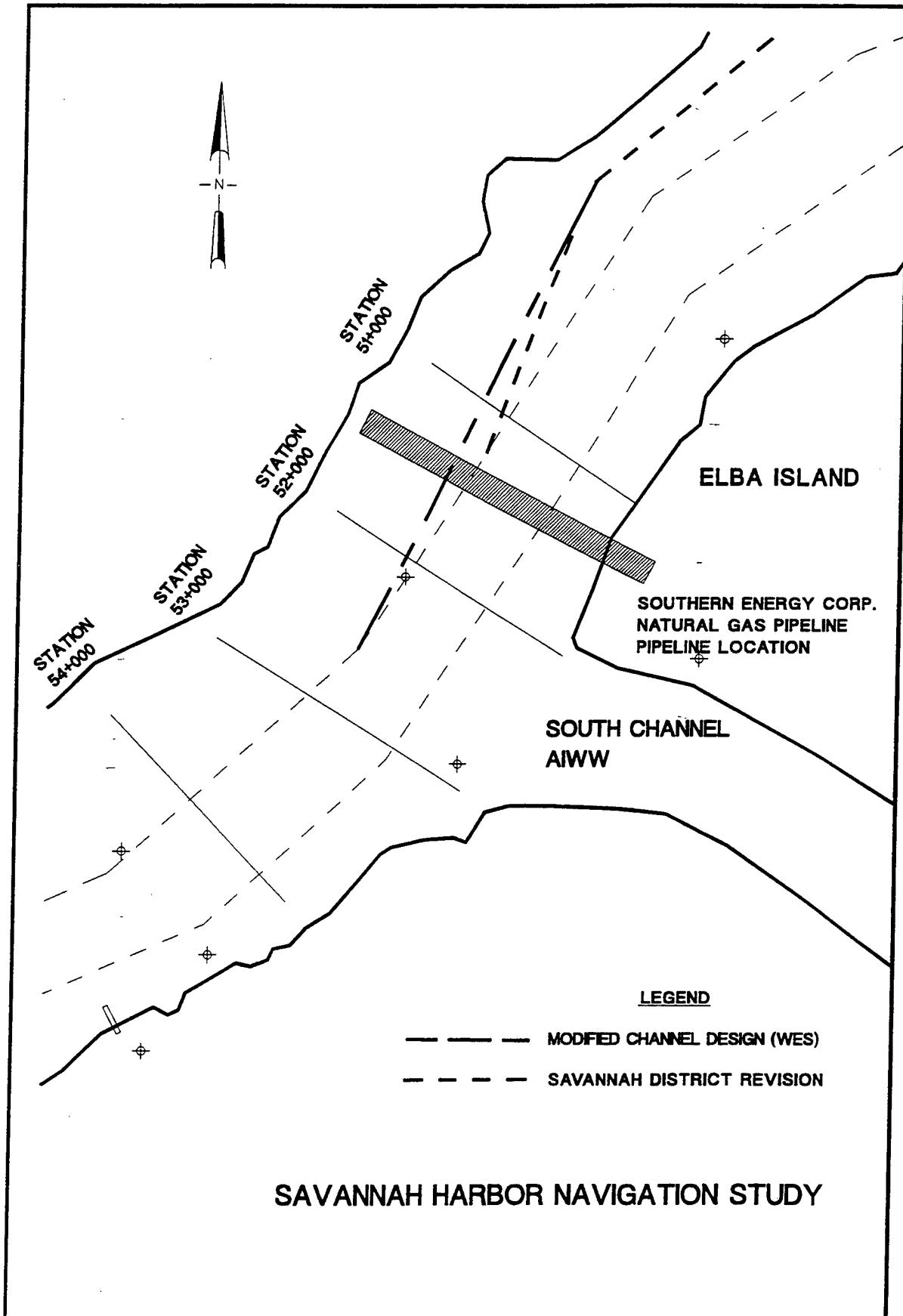


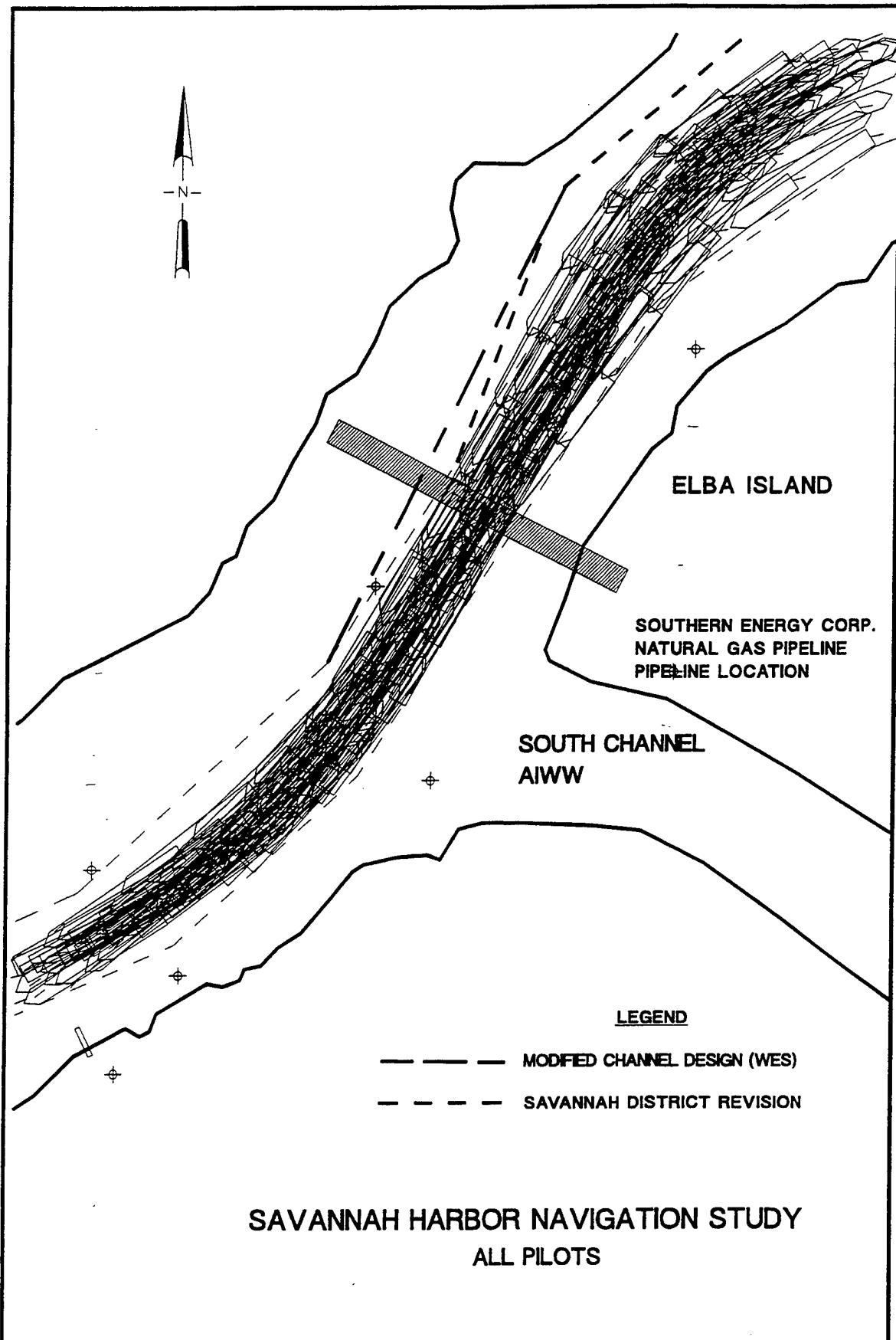












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13. ABSTRACT (Maximum 200 words) <p>The deepened channel design for the Savannah Harbor, Georgia, impacts ship maneuverability, underkeel clearance, and natural channel restrictions. There are also two changes affecting ship navigation: (a) the permanent opening of the tidal gate of Back River, and (b) the permanent closure of New Cut. The deepening impact on maneuvering in the Kings Island Turning Basin was minimal; however, the lower southeastern corner of Marsh Island Turning Basin, the bight upstream of the LNG Terminal, and the S-turn at the Atlantic Intracoastal Waterway (AIWW) should be widened. The widening in the bend downstream of the AIWW can be decreased.</p>				
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